Mapping and Modeling of Land Use and Land Cover in the Eastern United States From 1992 Through 2050

By Ryan R. Reker, Kristi L. Sayler, Aaron M. Friesz, Terry L. Sohl, Michelle A. Bouchard, Benjamin M. Sleeter, Rachel R. Sleeter, Tamara S. Wilson, Glenn E. Griffith, and Michelle L. Knuppe

Chapter 3 of

Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Eastern United States

Edited by Zhiliang Zhu and Bradley C. Reed

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Chapter 3. Mapping and Modeling of Land Use and Land Cover in the Eastern United States From 1992 Through 2050

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3.1. Highlights

- LULC maps at 250-m resolution were produced for each year of the baseline period of 1992 through 2005 and for three scenarios of future LULC change from 2006 through 2050. Modeling of terrestrial carbon stocks and fluxes, as detailed in chapter 7 of this report, used 2001 through 2005 as the baseline period.
- Forested ecosystems with large amounts of clearcutting generally had the highest rates of LULC change in all scenarios. Conversion to urban development was another significant change, particularly in ecoregions with large metropolitan areas. Conversion of forests to agricultural lands was significant in scenarios A1B and A2.
- The Southeastern USA Plains ecoregion had the greatest amount of change in the baseline period with 14.2 percent of the ecoregion changing LULC at least once and nearly 30 percent or greater changing LULC in all three scenarios of projected change.
- The Central USA Plains ecoregion had some of the lowest amounts of LULC change throughout the Eastern United States with less than 10 percent in each scenario and 2.6 percent during the baseline period.

3.2. Introduction

The spatial and temporal frameworks introduced in chapter 2 of this report serve as input to the spatial LULC modeling component described in this chapter. The mapping and modeling of LULC form the spatial foundations of this assessment and are used to define the composition of the assessed ecosystems. The LULC maps directly feed into other components of the assessment, particularly the assessment of GHG fluxes of aquatic systems (chaps. 5 and 6) and carbon storage and GHG fluxes of terrestrial systems (chap. 7).

LULC in the Eastern United States is diverse. Historically dominated by natural forests, the region now consists of a fragmented mosaic of urban areas, agricultural lands, areas of surface mining, and heavily managed forest lands. LULC change is equally as varied, with some areas undergoing rapid LULC change and others remaining relatively static, historically and projected into the future. The ecoregions for this assessment are defined in chapter 2 of this report.

This assessment uses a thematic classification system that represents a mix of LULC classes. The mixed LULC scheme enables the mapping and modeling of natural and anthropogenic processes that affect the landscape and, ultimately, biogeochemical cycles of GHGs. The temporal foundation of this assessment includes baseline data (data available for the historical period described in this chapter) and projected future data (generated through spatially modeled future scenarios, as described in chapter 2 of this report). Baseline and projected LULC data were used to guide the assessment of baseline and future changes in carbon storage and GHG fluxes. Spatial LULC modeling used to produce projected LULC maps consistent with the IPCC SRES, as described in chapter 2 of this report.

3.3. Methods and Data

3.3.1. Spatial Model Used for Mapping and Modeling

The spatial modeling framework FORE–SCE was used to produce annual LULC maps from 1992 through 2050. FORE–SCE has been used successfully in the past to model annual LULC change for large geographic regions (Sohl and Sayler, 2008; Sohl and others, 2012a,b). The FORE–SCE model uses separate but linked demand and spatial allocation components to produce spatially explicit, annual LULC maps. The demand component provides aggregate-level quantities of LULC change for a region or a prescription for the overall

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regional LULC proportions. The spatial allocation component ingests demand and produces spatially explicit LULC maps using a patch-based allocation procedure.

In the spatial allocation component, FORE–SCE uses suitability surfaces, unique to each modeled LULC class, to guide placement of new patches of LULC change on the landscape (Sohl and Sayler, 2008). Suitability surfaces are created using logistic regression to quantify empirical relationships between LULC and spatially explicit biophysical and socioeconomic variables. Suitability surfaces are made for each unique LULC class in every individually parameterized region or subregion that is modeled. Individual patches of new LULC are placed on the landscape for a given annual model run until demand is met for that given year. The process is repeated for each successive year until the modeling period is completed. Information on land under protected status can be used during spatial allocation procedures to restrict the placement of specific forms of LULC change on certain types of protected lands (for example, restricting urban development in national park lands).

The age of forest stands is also tracked spatially and temporally and can be estimated in the modeling environment in concert with the modeling of forest clearcuts, afforestation, and deforestation. In the FORE–SCE model, data about forest-stand ages are needed to ensure accurate modeling of clear-cutting cycles (based on the typical age when a forest stand is ready for harvesting) for a given geographic area and provide information on forest structure. The FORE–SCE model tracks forest-stand age for each annual model iteration and resets the stand age to 0 whenever a new forest area was generated or a forest was clearcut. Minimum cutting age thresholds can also be established for forest LULC classes to ensure harvest does not occur in forested areas of insufficient age. Additional details on the FORE–SCE model framework may be found in Sohl and Sayler (2008) and Sohl and others (2012a,b)

3.3.2. Starting LULC and Baseline Period

The baseline period permits an examination of recent LULC change and the calibration of the LULC and biogeochemical modeling processes before the simulations of projected future conditions. A modified version of the 1992 NLCD (Vogelmann and others, 2001) served as the initial LULC data for this work. The start of the baseline period was set to 1992 because it marked the earliest year for which consistent, nationwide, satellite-derived LULC data were available. NLCD data were available for 1992, 2001, and 2006 (Vogelmann and others, 2001; Homer and others, 2007; Xian and others, 2009), but annual maps were not available, and different mapping methodologies between NLCD versions precluded the use of the NLCD alone for providing LULC data for the 1992 through 2005 baseline period. Annual LULC maps for the baseline period were required to adequately portray gross changes between LULC classes that could be missed by a temporal interval longer than 1 year and thus could affect carbon and GHG calculations. The endpoint of the baseline period was set to 2005. The latest NLCD data available at the time of the assessment was conducted were from the 2006 NLCD (Xian and others, 2009), but 2005 was chosen as the end date for the baseline period to facilitate the use of equal 5-year intervals for construction of the projected scenarios.

The NLCD thematic classification system could be directly generalized to the primary ecosystem types analyzed for this assessment (table 1–1). The original resolution of the 1992 NLCD was 30 m, but the data were resampled to 250 m for this assessment to reduce the volume of data and hold the modeling requirements to a consistent level. Several adjustments were made to the thematic classes for practical considerations and to improve the ability of the modeling framework to address LULC impacts on carbon and GHG fluxes. The four urban classes from the 1992 NLCD were collapsed into one urban/developed class, because separate categories were not required to explicitly model detailed urban class changes for the conterminous United States. Similarly, three agricultural lands classes from the 1992 NLCD (row crop, small grains, and fallow) were collapsed into one agriculture lands class that represented cultivated crops.

The classification scheme was also altered to include classes representing forest clearcutting (mechanically disturbed), because forest management and clearcutting can affect significantly not only biogeochemical cycling, but other ecological processes as well. The thematic labeling of forest clearcuts allowed for tracking and modeling of clearcut locations and the resulting effect on forest structure, while recognizing that the underlying forest land use had not changed. The 1992 NLCD dataset was augmented (fig. 3–1) by incorporating information from the Vegetation Change Tracker (VCT; Huang and others, 2010) of the Landscape Fire and Resource Management Planning Tools Project. The VCT data mapped natural and anthropogenic disturbances, particularly forest clearcuts and wildland fires, by analyzing stacked images from the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+). Wildfires were extracted from the VCT data using fire locations from the Monitoring Trends in Burn Severity Project (MTBS; Eidenshink and others, 2007). Data on contemporary rates of forest clearcutting and spatial information on clearcut patch characteristics from the USGS Land Cover Trends Project were subsequently used to filter the VCT data to approximate locations of clearcut forest harvests. Clearcut forest locations derived from edited VCT data from the baseline period were used to populate mechanically disturbed classes 3, 4, and 5 (table 1–1) for the starting 1992 land cover. The LULC class mechanically disturbed derives from the USGS Land Cover Trends Project (Auch and others, 2012; Napton and others, 2010; Sleeter and others, 2012a,b) and is used in this report to refer to forest clearcutting for the harvest of timber resources exclusively.

The three mechanically disturbed classes are differentiated as national forest, other public land, and private land

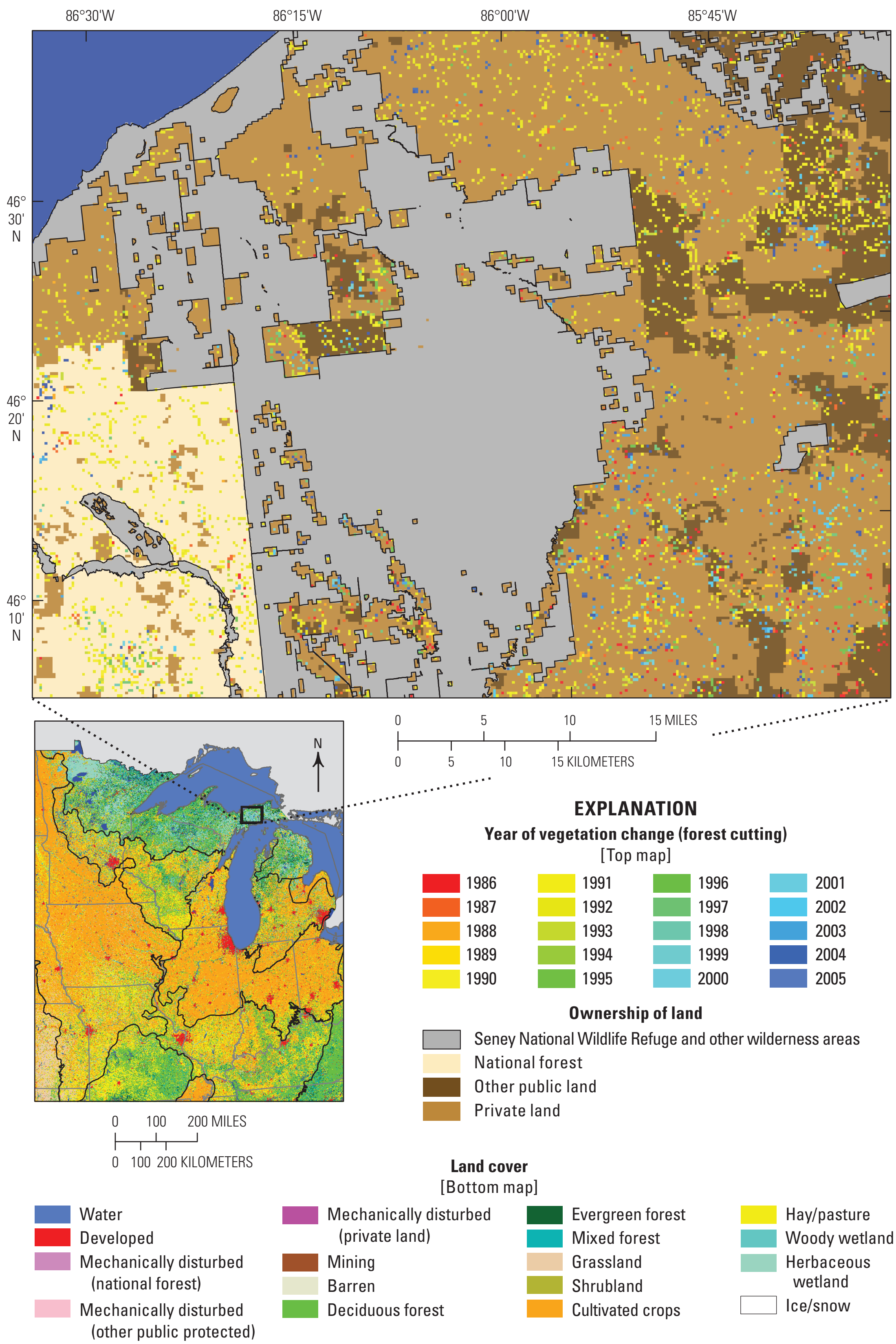


Figure 3–1. Map showing how data from the vegetation change tracker of Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) provided information on ecosystem disturbances for the assessment of carbon fluxes and storage in the Eastern United States.

based on ownership and protection status. The Protected Area Database of the United States (PAD–US; Protected Areas Database of the United States Partnership, 2009) was used to spatially distinguish ownership for the three disturbance classes. The PAD–US database includes Federal, State, and local protected lands, as well as information from national nonprofit organizations. The database does not cover all protected lands (for example, conservation easements), but it is the most comprehensive and accurate protected lands database available for the United States. In this framework, the mechanically disturbed classification is used strictly to represent a temporary land cover status within the overall land use class of forest. When a forest parcel is clearcut, the mechanically disturbed label is temporarily applied to the parcel. Timber on parcels labeled as mechanically disturbed can thus be assumed to have been recently harvested, and the parcel is still assumed to be managed as a forested land use. The framework of the assessment makes the assumption that the forest cover regenerates over time after the clearcut, and after an average of seven years, the thematic label returns to the original forest class. Although forest use does not change for areas that have been clearcut, the temporary use of the mechanically disturbed label allows tracking, quantifying, and modeling forest cutting and forest stand age.

The demand component of FORE–SCE for the LULC change in the baseline period was separated into two periods to take advantage of temporally specific historical data. Demand from 1992 through 2000 was provided by USGS land cover trends data (U.S. Geological Survey, 2012). The USGS Land Cover Trends Project used a sampling approach and the historical archive of Landsat data to produce estimates of LULC change for each of 84 level III ecoregions (modified from U.S. Environmental Protection Agency, 1999) in the conterminous United States (Loveland and others, 2002). Although the coarse-scale level II ecoregion framework was used for the overall assessment in the Eastern United States, the fine-scale level III ecoregion framework served as the primary framework for all FORE–SCE-based LULC modeling, which improved the representation of spatial LULC change patterns in a heterogeneous landscape.

Demand information from the USGS Land Cover Trends Project was provided separately for each level III ecoregion, and the spatial allocation component of FORE–SCE was parameterized individually for each level III ecoregion. From 1992 through 2000, USGS land cover trends data provided baseline regional proportions of LULC change; however, these data were thematically less detailed than the LULC classes used for this assessment as shown in table 1–1. For example, USGS land cover trends only estimated one aggregate forest class, whereas this assessment differentiated between deciduous, evergreen, and mixed forest types. To obtain the three forest types and their transitions from the USGS land cover trends data from 1992 through 2000, the proportions of the three forest types from the 1992 NLCD were used to disaggregate the USGS land cover trends single forest class for each level III ecoregion. A similar disaggregation of USGS land cover trends classes using the 1992 NLCD was performed to split the USGS land cover trends class grasslands/shrublands into the grassland and shrubland classes, split wetland into the herbaceous wetland and woody wetland classes, and split agricultural lands into hay/pasture and cultivated crop. Finally, the estimates for 1992 through 2000 by ecoregion were annualized to produce annual rates of change that served as annual demand for the FORE–SCE model.

A similar methodology was used to populate the demand component of the model for 2001 through 2005. The demand for this period was provided by the 2001 through 2006 NLCD change data (Xian and others, 2009). The 2001 and 2006 NLCD data provided a LULC change product that provided consistent, wall-to-wall LULC data for the conterminous United States. The level of thematic detail was mostly compatible with this assessment, and unlike the USGS land cover trends data for 1992 through 2000, no disaggregation to a finer thematic scale was necessary. The 2001 through 2006 NLCD change data were annualized to produce rates of change that served as annual demand for 2001 through 2005 for the FORE–SCE model.

3.3.3. Projection Period

The timeframe of 2006 through 2050 served as the projected LULC modeling period. The scenarios (chap. 2) served as input to the FORE–SCE spatial modeling framework, with FORE–SCE producing spatially explicit representations for each of the three SRES scenarios. Spatial resolution (250 m), temporal characteristics (annual LULC maps), and thematic resolution (table 1–1) were consistent with the baseline period, resulting in a consistent, continuous series of LULC maps between the baseline and projected periods (annual LULC maps from 1992 through 2050).

Regional LULC storylines were downscaled to formulate future alternative landscape scenarios (chap. 2). These scenarios provided quantitative prescriptions of future landscape composition that were used in conjunction with spatial modeling to create a suite of LULC maps from 2006 through 2050. The FORE–SCE model served as the primary modeling framework for ingesting scenario storylines and producing the spatially explicit LULC projections. As with the baseline LULC modeling, the demand component of the framework again supplied overall proportions of LULC change at a regional level, and the spatial allocation component ingested those proportions and produced spatially explicit LULC maps. Demand for the LULC projection period of 2006 through 2050 was supplied by the quantified scenarios described in chapter 2. For this assessment, a version of FORE–SCE was used that ingests and models specific LULC transitions; for example, each scenario provided a quantified matrix of LULC transitions for a given annual model run. FORE–SCE used the same suitability surfaces as in the baseline period to guide the placement of individual patches of landscape change.

The last year (2005) of the mapped and modeled baseline period served as the starting point for the LULC projections.

The 2005 forest stand age layer from the baseline runs provided the starting stand age layer for the projected LULC model runs. The PAD–US data again were used to spatially partition portions of the landscape with a protected status, but for the projected period, the implementation of the PAD–US data was dependent upon scenario. More forms of protected lands in the PAD–US were protected from LULC change in the environmentally focused scenario B1 than in the economically focused scenarios A1B and A2, resulting in a potentially different spatial configuration of LULC change between scenarios even if the prescribed LULC proportions from the scenarios were the same. Parameterization of the FORE–SCE model was again conducted for each level III ecoregion, but for the projected period, parameterization differed across scenarios. For example, a dispersion variable was used to determine what proportion of the suitability surface histogram is open to LULC change. For a scenario such as A1B, urban development may be allowed to occur on a wider part of the suitability surface histogram, resulting in a more dispersed urban footprint that represents urban sprawl. Conversely, for an environmental scenario such as B1, assumptions of compact urban development led to a tightening of the dispersion variable, resulting in smaller, more compact urban footprints. Individual patch characteristics may also differ between scenarios, as dictated by the qualitative scenario storylines.

Modeling within the FORE–SCE framework was conducted with annual model iterations, by level III ecoregion, with patches of LULC change placed on the landscape until demand for a given annual run was met for that ecoregion. Processing then continued to each subsequent year until the 2006 through 2050 period was complete. The modeled LULC change for 2006 through 2050 thus provided plausible spatial representations for each of the three SRES scenarios. When combined with the mapped and modeled baseline LULC maps, the LULC mapping and modeling work described in this section resulted in a continuous, annual, consistent LULC map database from 1992 through 2050.

3.4. Results and Discussion

3.4.1. Baseline LULC Mapping and Modeling

To understand LULC change in the Eastern United States, it is often necessary to discuss changes in individual LULC classes nested within the ecosystems. The following discussion of results provides a summary of ecosystems defined for this assessment, as well as a discussion of nested LULC classes where appropriate. Ecosystem composition in the Eastern United States at the beginning of the baseline period was dominated by forests with 48.1 percent (1,467,167 km^2) and agricultural lands with 31.9 percent (972,486 km^2), combining for 80 percent (2,439,652 km^2) of the region. Remaining ecosystems consisted of other lands with 9.5 percent (290,470 km^2), wetlands with 8.9 percent (272,486 km^2), and grasslands/shrublands with 1.6 percent (50,168 km^2). Two LULC classes nested within the ecosystem categories warrant special attention for their effects on carbon and GHG dynamics and status as primary drivers of land change in the Eastern United States. The three mechanically disturbed classes are part of the forests ecosystem and represent 3.2 percent (46,168 km^2) of the ecosystem and 1.5 percent of the total Eastern United States. Changes in forest ecosystem area affect all six nested LULC forest classes (deciduous, evergreen, and mixed forests and the three mechanically disturbed classes) to reflect total changes in forest area via conversions to other ecosystem classes (that is, developed or agricultural lands). LULC changes in the mechanically disturbed class reflect transitional changes within the forest lands ecosystem, indicating changing rates of forest harvest, but these changes do not affect overall ecosystem area. The developed class is nested within the other lands ecosystem, making up 41.1 percent (119,413 km^2) of the class and 3.9 percent of the total region.

The LULC change footprint is defined as the percentage of the Eastern United States or an ecoregion that changed LULC type at least once during the time period (Sleeter and others, 2012a,b; Wilson and others, 2012). During the baseline period, approximately 8 percent (244,331 km^2) of the Eastern United States changed at least once (fig. 3–2; table 3–1). The developed, other lands, and mechanically disturbed classes contributed the most to the footprint of LULC change of the Eastern United States through unidirectional conversions to urban lands and the cyclical nature of forest harvest and subsequent regeneration.

Developed land led all LULC classes in net change with an increase of 19.4 percent (23,186 km^2) in urban area (fig. 3–3; table 3–2). LULC change in the other lands ecosystem class showed a change of 8.9 percent, with most of the categories within the class showing little change, aside from mining, which saw a net increase of 29.5 percent (1,355 km^2). Water area increased by only 0.8 percent (1,381 km^2), and changes in the barren and ice/snow categories were relatively minor.

LULC change in the forests ecosystem (including deciduous, evergreen, and mixed forest cover types and mechanically disturbed LULC classes) appeared relatively stable during the baseline period, decreasing by only 0.4 percent (5,700 km^2). Within the forests ecosystem, LULC in the three mechanically disturbed classes experienced a total net increase of 8.3 percent (9,525 km^2; table 3–2) with most of the gains occurring on private lands (11.4 percent, 4,760 km^2). More than 90 percent of all forest cutting in the Eastern United States was on private lands with that trend continuing throughout the baseline period (fig. 3–4). Gains in area by the mechanical disturbance classes reflect decreases in area of the forested LULC classes, indicating an increase in the rate of forest clearcutting. A variety of factors contributed to more intensive forest clearcutting in the Eastern United States during the baseline period. In the southern half of the region, the shift towards increased private industrial forest management of

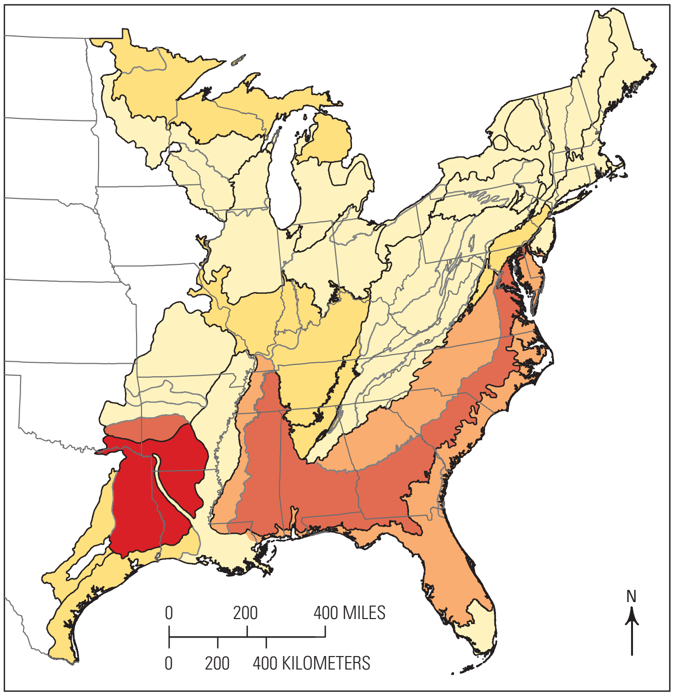


Figure 3–2. Map showing spatial variability of land-use and land-cover change in the Eastern United States.

intensely cultivated pine monocultures was already occurring, and the trend continued throughout the baseline period (Binford and others, 2006). On a managed pine plantation, harvest cycles for timber products can be as short as 20 to 25 years, enabling multiple harvests in the same amount of time it takes to make a single cutting in more temperate forests. Production in the Southeastern United States also increased due to timber harvest decreases in the Pacific Northwest (Haynes, 2003; Drummond and Loveland, 2010).

LULC change in the agricultural lands ecosystem class decreased by more than 2.1 percent (20,471 km^2) during the baseline period. Modern losses in agricultural lands have been well documented by contemporary studies of LULC change in the Eastern United States (Brown and others, 2005; Drummond and Loveland, 2010). Decreasing profitability associated with farming marginal land led to losses of nearly 2 percent each in cropland (10,773 km^2) and hay/pasture (9,698 km^2) to forest lands through abandonment, conversion to managed timber production, or government conservation programs, such as the Conservation Reserve Program (CRP).

LULC change in the grasslands/shrublands ecosystem increased by 2.3 percent (1,138 km^2) during the baseline period, mostly due to enrollment of agricultural lands into the CRP in western parts of the region, such as the East Central Texas Plains level III ecoregion, where agricultural lands conversion was more suited to native and managed grasses. The wetlands ecosystem class encompassed 8.9 percent (272,422 km^2) of the Eastern United States and remained fairly static during the baseline period, with wetland losses of 0.4 percent (959 km^2).

The LULC footprint closely reflected the spatial variability of the two major types of land change, developed and forest clearcutting, with each class displaying vastly different spatial patterns from the other. Several level III ecoregions

Table 3–1. Land-use and land-cover change footprint in the Eastern United States from 1992 through 2005.

[km^2, square kilometers]

Ecoregion	Area, in km^2	Percentage change
Mixed Wood Shield	215,648	7.6
Atlantic Highlands	187,551	2.3
Mixed Wood Plains	388,858	2.9
Central USA Plains	239,027	2.6
Southeastern USA Plains	994,355	14.2
Ozark, Ouachita-Appalachian Forests	520,486	4.2
Mississippi Alluvial and Southeast USA Coastal Plains[1]	506,807	8.4
Eastern United States (total)	**3,052,732**	**8.0**

[1]Includes the Everglades and Texas-Louisiana Coastal Plain level II ecoregions for the analysis of this assessment.

with large amounts of forest clearcutting and developed lands had LULC change footprints of 40 percent or more (fig. 3–5). A brief examination of the basic characteristics of the seven level II ecoregions and major driving forces of LULC change in the ecoregions is provided in chapter 2.

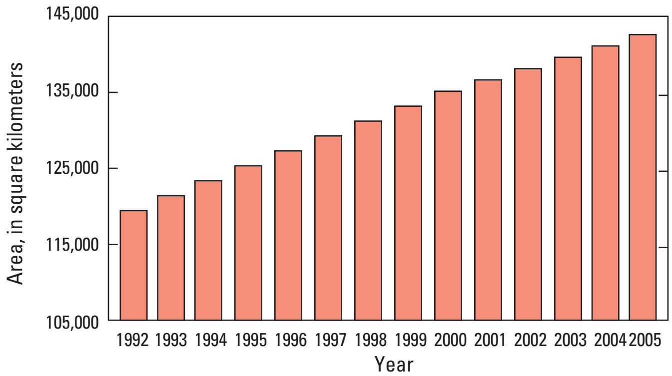


Figure 3–3. Chart showing the increasing trend in the areal extent of the developed land-use and land-cover class in the Eastern United States between 1992 and 2005.

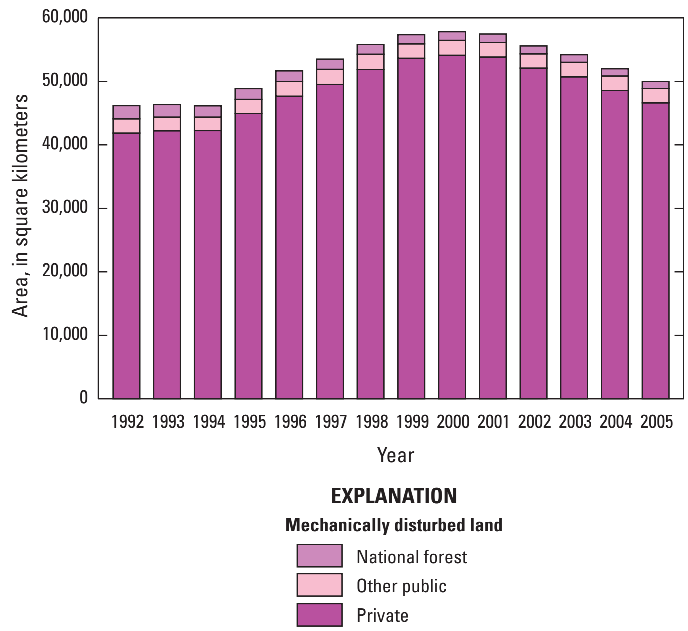
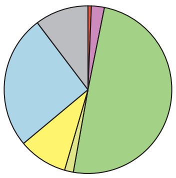
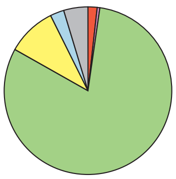
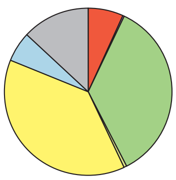
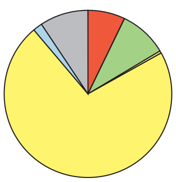
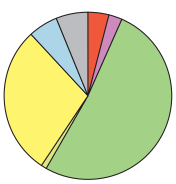
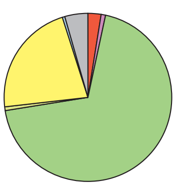
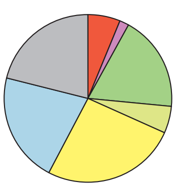


Figure 3–4. Chart showing the increasing trend of forest clearcutting in the Eastern United States between 1992 and 2005. Private lands make up the largest share of timber harvest and also saw the greatest gains. The greatest declines were noted on national forest lands.

Table 3–2. Mapped and modeled land use and land cover in the Eastern United States from 1992 through 2005.

[km^2, square kilometers]

Ecosystem class	Area, in km^2		Change between 1992 and 2005	
	1992	2005	Area, in km^2	Percentage
Forests	1,467,167	1,461,467	5,700	–0.4
Agricultural lands	972,486	952,014	–20,471	–2.1
Other lands	290,470	316,463	25,993	8.9
Wetlands	272,442	271,483	–959	–0.4
Developed	119,413	142,598	23,186	19.4
Grasslands/shrublands	50,168	51,306	1,138	2.3
Mechanically disturbed	46,168	49,993	3,825	8.3

	Land-use or land-cover class						
	Developed	Mechanically disturbed	Forests	Grasslands/ shrublands	Agriculture	Wetlands	Other lands
Mixed Wood Shield ecoregion							
1992 (area km²)	1,356	5,407	110,707	3,614	20,977	57,483	22,867
2005 (area km²)	1,453	5,581	110,556	3,796	20,986	57,336	22,973
Net change in area (in km²)	97	175	-151	182	9	-147	106
Change in area (in percent)	7.1	3.2	-0.1	5.0	0.0	-0.3	0.5
Atlantic Highlands ecoregion							
1992 (area km²)	3,165	895	155,271	272	18,252	5,120	8,637
2005 (area km²)	3,385	981	154,954	306	18,195	5,123	8,973
Net change in area (in km²)	219	86	-316	34	-57	3	336
Change in area (in percent)	6.9	9.6	-0.2	12.4	-0.3	0.1	3.9
Mixed Wood Plains ecoregion							
1992 (area km²)	24,380	1,380	149,476	2,023	162,651	24,257	50,452
2005 (area km²)	28,401	1,185	147,983	2,247	159,757	24,231	54,639
Net change in area (in km²)	4,021	-195	-1,493	224	-2,893	-26	4,188
Change in area (in percent)	16.5	-14.1	-1.0	11.1	-1.8	-0.1	8.3
Central USA Plains ecoregion							
1992 (area km²)	14,296	62	24,219	1,001	189,424	4,678	19,706
2005 (area km²)	18,427	61	23,787	1,175	185,336	4,675	24,055
Net change in area (in km²)	4,131	-1	-432	174	-4,089	-3	4,349
Change in area (in percent)	28.9	-1.4	-1.8	17.4	-2.2	-0.1	22.1
Southeastern USA Plains ecoregion							
1992 (area km²)	34,573	26,819	550,271	10,999	316,505	60,373	56,207
2005 (area km²)	42,990	27,757	550,030	11,262	306,678	60,763	65,623
Net change in area (in km²)	8,418	939	-241	263	-9,828	390	9,416
Change in area (in percent)	24.3	3.5	-0.0	2.4	-3.1	0.6	16.8
Ozark, Ouachita-Appalachian Forests ecoregion							
1992 (area km²)	11,605	3,352	374,361	3,550	118,434	2,571	21,570
2005 (area km²)	13,611	4,569	372,212	3,903	117,760	2,592	24,020
Net change in area (in km²)	2,007	1,217	-2,149	353	-674	21	2,450
Change in area (in percent)	17.3	36.3	-0.6	9.9	-0.6	0.8	11.4
Mississippi Alluvial and Southeast USA Coastal Plains ecoregion							
1992 (area km²)	30,037	8,253	102,863	28,709	146,244	117,960	111,032
2005 (area km²)	34,331	9,858	101,945	28,618	143,304	116,763	116,179
Net change in area (in km²)	4,293	1,604	-918	-92	-2,940	-1,198	5,147
Change in area (in percent)	14.3	19.4	-0.9	-0.3	-2.0	-1.0	4.6

EXPLANATION

[Pie charts represent data for 2005]

Land-use and land-cover class

Developed
Mechanically disturbed
Forests
Grasslands/ shrublands
Agriculture
Wetlands
Other

Figure 3–5. Charts showing the proportions of land-use and land-cover (LULC) by level II ecoregion at the end of the baseline period (pie charts for 2005) and the net change in the mapped and modeled LULC classes between 1992 and 2005.

3.4.2. Projected LULC Mapping and Modeling

The projected changes in LULC were variable across scenarios and ecoregions of the Eastern United States. Under the scenarios used for this assessment, the projected LULC change footprint ranged from a low of 17.2 percent in scenario B1 to the highs of 22.9 percent in scenario A1B and 20.8 percent in scenario A2 (fig. 3–6; table 3–3). The scenarios that indicated the greatest (A1B) and smallest (B1) amounts of projected LULC change shared the same population assumptions; however, the focus on economic growth in scenario A1B resulted in higher demand for forest products, urban growth, and agricultural intensification contributing to greater overall amounts of LULC change than in scenario B1. Scenario B1 was characterized by strengthening environmental protections and more resource-friendly lifestyles, which limited anthropogenic conversion of natural land covers to urban or agricultural lands LULC. The demand for forest products and agricultural commodities was reduced in scenario B1 compared with scenario A1B, and the environmental emphasis associated with scenario B1 resulted in a more compact pattern of urbanization than in scenario A1B. Similar to scenario A1B, scenario A2 focused on economic growth. However, with a regional focus on growth as opposed to globalization that characterized scenario A1B, economic growth was muted in comparison to scenario A1B, resulting in more moderate amounts of forest cutting, agricultural expansion, and urban growth by 2050. The LULC change footprints for all scenarios in the Southeastern USA Plains ecoregion were near or greater than 30 percent, whereas the LULC change footprints for all scenarios in the Central USA Plains ecoregion were less than 10 percent (fig. 3–5).

Spatial patterns of developed growth varied within the Eastern United States as well. Generally, urban growth occurred where high-population cities already existed. High growth in the developed LULC class occurred in the Southeastern USA Plains ecoregion, which contained 30 percent (42,990 km^2) of all developed lands in the Eastern United States, and increased by 66 percent in scenario B1 to 92.9 percent (39,946 km^2) in scenario A1B. Urban growth in the ecoregion centered on the large metropolitan centers of Atlanta, Georgia; Washington, D.C.; and New York City, New York. In contrast, the Mixed Wood Shield ecoregion ranked near the bottom in developed growth with a 24.9 percent (361 km^2) increase in scenario B1 to a high of 49.4 percent (717 km^2) in scenario A1B. The Mixed Wood Shield ecoregion contained only 1 percent (1,453 km^2) of all developed lands in the Eastern United States clustered in small cities, such as Duluth, Minnesota, and Marquette, Michigan.

Changes in the extent of agricultural lands occurred mostly in regions with a mixture of agricultural lands and forest ecosystems, such as the Southeastern USA Plains ecoregion, which was an area that had the highest LULC change footprint in the Eastern United States at nearly one-third of the ecoregion in all three scenarios and a fairly balanced distribution of agricultural lands (30.8 percent, 306,678 km^2) and forests (55.3 percent, 550,030 km^2) at the start of the projection period. In scenario A1B, which had the highest LULC change footprint of all scenarios, 88.1 percent of the agricultural lands class in 2006 remained stable in 2050. In scenario A1B, the Southeastern USA Plains ecoregion had a relatively low degree of agricultural stability compared with ecoregions where forests or agricultural lands dominate the landscape.

The Central USA Plains ecoregion predominantly comprises agricultural lands (79.3 percent, 185,336 km^2) with a small amount of lands as forests (10 percent, 23,787); the ecoregion had the lowest LULC change footprint (less than 10 percent) across all scenarios. The ecoregion is part of the highly fertile Corn Belt, a productive agricultural region with little new land available for conversion to agricultural lands. Other ecoregions with less fertile soils would be more likely to lose agricultural lands before this core area of the Corn Belt. As a result, the 98.7 percent of the agricultural lands class in 2006 remained unchanged in 2050 in scenario A1B. In heavily forested ecoregions, such as the Atlantic Highlands ecoregion, which had more forests (82.6 percent, 154,954 km^2) than agricultural lands (9.7 percent, 18,195 km^2) at the start of the projection period, increases in agricultural lands were restricted by poor soils, terrain, and climate. The relatively small amounts of agricultural lands LULC at the start of the projection period made large-scale decreases in the

Table 3–3. Projected land-use and land-cover change footprint in the Eastern United States.

[IPCC, Intergovernmental Panel on Climate Change; km^2, square kilometers; SRES, Special Report on Emission Scenarios (Nakićenović and others, 2000). km^2, square kilometers]

Ecoregion	Area, in km^2	IPCC SRES scenario, percentage change		
		A1B	A2	B1
Mixed Wood Shield	215,648	29.9	27.6	13.3
Atlantic Highlands	187,551	22.9	22.1	14.2
Mixed Wood Plains	388,858	13.1	13.9	7.3
Central USA Plains	239,027	9.3	7.5	4.6
Southeastern USA Plains	994,355	33.2	29.5	30.6
Ozark, Ouachita-Appalachian Forests	520,486	20.5	19.7	10.6
Mississippi Alluvial and Southeast USA Coastal Plains[1]	506,807	16.1	13.1	13.9
Eastern United States (total)	**3,052,732**	**22.9**	**20.8**	**17.2**

[1]Includes the Everglades and Texas-Louisiana Coastal Plain level II ecoregions for the analysis of this assessment.

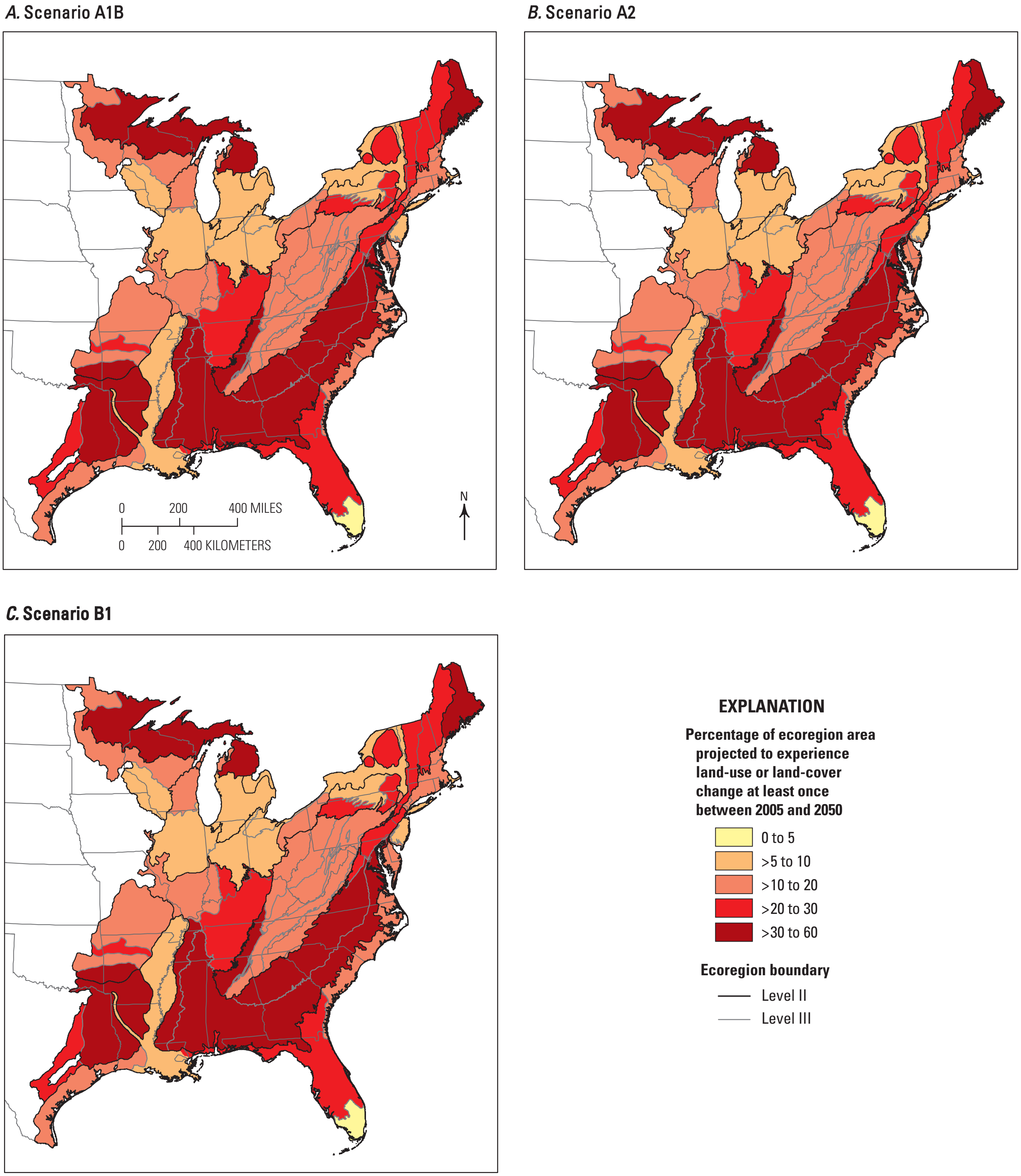


Figure 3–6. Maps showing the projected land-use and land-cover change footprint for the level II and III ecoregions of the Eastern United States. The footprint represents the percentage of the ecoregion that changed at least once between 2005 and 2050. *A*, Scenario A1B; *B*, scenario A2; *C*, scenario B1.

agricultural lands class unlikely as well. These factors contributed to the 91 percent of agricultural lands in 2006 remaining unchanged by 2050 in scenario A1B.

Aside from conversions to developed lands, change in the forests class was generally linked to change in agricultural lands, so that increases in agricultural lands LULC classes from forested LULC classes were more than 85 percent in scenario A1B and more than 90 percent in scenario A2, leading to net decreases of the forests ecosystem class in both scenarios. Forest LULC generally increased across the Eastern United States in the more environmentally oriented scenario B1 as demand for agricultural goods decreased and focus shifted to restoration of natural land cover types.

Forest clearcutting was the single largest LULC change in the Eastern United States during the projected period, contributing extensively to the region's overall LULC change. Projected forest harvest (the sum of the areas between 2006 and 2050 that experienced clearcut logging) exceeded net increases in developed lands by a wide margin across scenarios (fig. 3–7). Developed LULC change affected a smaller area of the Eastern United States and was concentrated near existing cities; however, this LULC class is unidirectional and more permanent than forest clearcutting. Forest harvest and regrowth is more cyclical developed change because the same forest parcel can be harvested multiple times during the projection period and harvest widely occurs throughout the region. Forest clearcutting rates and trajectories varied across scenarios during the projection period (fig. 3–8).

Forest use assumptions associated with scenario A1B led to a rapid increase in timber harvest early in the projection period and remained the highest cutting scenario overall, with forest harvest increasing by 541.9 percent (5,315 km^2) in the Atlantic Highlands ecoregion and 162.2 percent (7,410 km^2) in the Ozark, Ouachita-Appalachian Forests ecoregion. Forest cutting increased at a less steep rate in scenario A2 than in scenario A1B, but narrowed the gap in area of forest lands harvested toward the end of the projected period to end just slightly lower than scenario A1B. Overall forest cover decreased in scenarios A1B and A2, whereas forest clearcutting increased. Forest cutting increased slightly early in scenario B1, but the overall rate of harvesting decreased by 6.9 percent (3,430 km^2) to end up lower than at the beginning of the projection period. Forest cutting continued a diverse regional pattern in scenario B1 with cutting rates increasing by 204.5 percent (2,006 km^2) in the Atlantic Highlands ecoregion but decreasing in other ecoregions by as much as 53.8 percent (5,305 km^2) in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion. Details of the projected results for the seven ecoregions are presented in the next section.

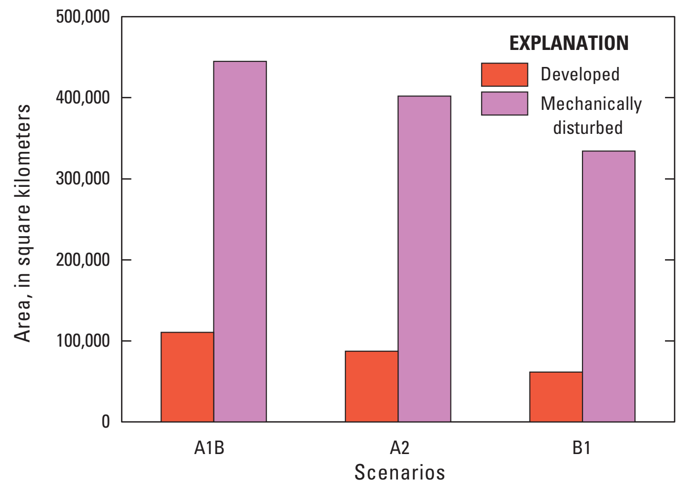


Figure 3–7. Graph showing comparison between mechanically disturbed and developed land use classes in the Eastern United States for three land-use and land-cover scenarios (Nakićenović and others, 2000).

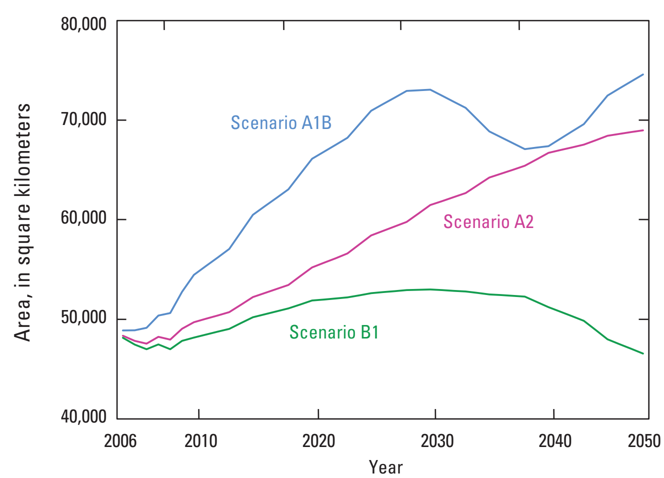


Figure 3–8. Graph showing trends for mechanically disturbed land use in the Eastern United States for the projected period (2006 through 2050).

3.4.3. Projections of Land Use and Land Cover Patterns in the Eastern United States From 2006 Through 2050

3.4.3.1. Mixed Wood Shield

During the projected period (2006–2050) for the assessment of carbon fluxes and storage in the Eastern United States, the footprint of LULC change in the Mixed Wood Shield ecoregion for each scenario was relatively high compared with that in other ecoregions in the Eastern United States. Scenario A1B had the greatest amount change, with 29.9 percent of the land area changing at least once (table 3–3). Scenario A2 had the second highest amount of change (27.6 percent), whereas scenario B1 had the lowest amount (13.3 percent). There was little to no spatial variability in the amount of LULC change between level III ecoregions depending upon the presence and (or) amount of forest clearcutting.

The Northern Minnesota Wetlands level III ecoregion consists of a mix of LULC types with little forest harvest. In the highest changing scenario, A1B, only 10.8 percent (2,590 km^2) of LULC changed, whereas in scenarios A2 and B1, only 9.8 percent (2,359 km^2) and 6.2 percent (1,486 km^2), respectively, of LULC changed.

In the more forested Northern Lakes and Forest ecoregion, LULC change was much higher than in other level III ecoregions in the Eastern United States due to forest harvest, with change in scenarios A1B, A2, and B1 amounting to 32.4 percent (61,984 km^2), 29.8 percent (57,145 km^2), and 14.2 percent (27,100 km^2), respectively. In the economically focused scenarios A1B and A2, change was driven primarily by the increase in forest use (represented by increased rates of clearcutting) and by the expansion of developed and agricultural lands within the ecoregion. The extent of forest clearcutting in scenario A1B increased by 78.3 percent (4,371 km^2) between 2006 and 2050 even though the forests ecosystem (forest and mechanically disturbed LULC classes) was reduced by 5.8 percent (6,371 km^2). Scenario A2 had an increase of 64.5 percent (3,602 km^2) in the extent of forest clearcutting, while also losing 5.8 percent (6,411 km^2) of the total forest ecosystem area.The economically focused scenarios saw increases in the extents of developed and agricultural lands. The extent of developed lands in scenario A1B increased by 49.4 percent (717 km^2), whereas in scenario A2, the extent of developed lands increased by 44.4 percent (646 km^2). The decrease in the extent of the forests ecosystem contributed the most to increases in the extent of developed lands. In scenario A1B, 85.6 percent (597 km^2) of the gains in the extent of developed lands came from forests, whereas in scenario A2, 79.4 percent (553 km^2) of the gains came from forests. The story was the same for agricultural lands as well. The economic scenarios A1B and A2 experienced increases in the extent of agricultural lands, undergoing increases of 21.5 percent (4,508 km^2) and 21.1 percent (4,435 km^2), respectively, in extent. Gains in the extent of agricultural lands from forests totaled 89 percent (4,011 km^2) in scenario A1B and 91.7 percent in scenario A2.

LULC change in scenario B1 varied from the changes experienced in the economic scenarios, with the extent of the forested ecosystem decreasing slightly (1.9 percent; 2,106 km^2) and the extent of forest clearcutting reduced by 48.1 percent (2,682 km^2). In this environmentally conscious scenario, the extent of developed lands increased by 24.9 percent (361 km^2), a much lower extent than in the economically focused scenarios, and the extent of agricultural lands saw a minor decrease of about 1 percent. Increases in the extent of developed lands in this scenario came primarily from forests (79.4 percent, 287 km^2) and, to a lesser extent, from agricultural lands.

An example of typical LULC change in the Mixed Wood Shield ecoregion is the area around Duluth, Minnesota, and Superior, Wisconsin (fig. 3–9). Encroachment into forested areas by developed lands around these cities can be seen in all scenarios. Agricultural expansion, due to the growing population and the market demand for agricultural commodities around Duluth and Superior can be seen in all scenarios, although to a lesser extent in scenario B1. Differences in the forest characteristics of the economically driven scenarios versus the environmentally oriented scenario are stark and driven by scenario assumptions. In scenarios A1B and A2, where high pressure is placed on forest resources, clearcutting can be seen throughout the entire area. In contrast, the extent of forest clearcutting in scenario B1 is much less dramatic. Although clearcutting in scenario B1 possesses a similar geographic distribution as in the economic scenarios, the large concentrations of clearcut areas are absent, and the extent of forest gains are higher, albeit scattered.

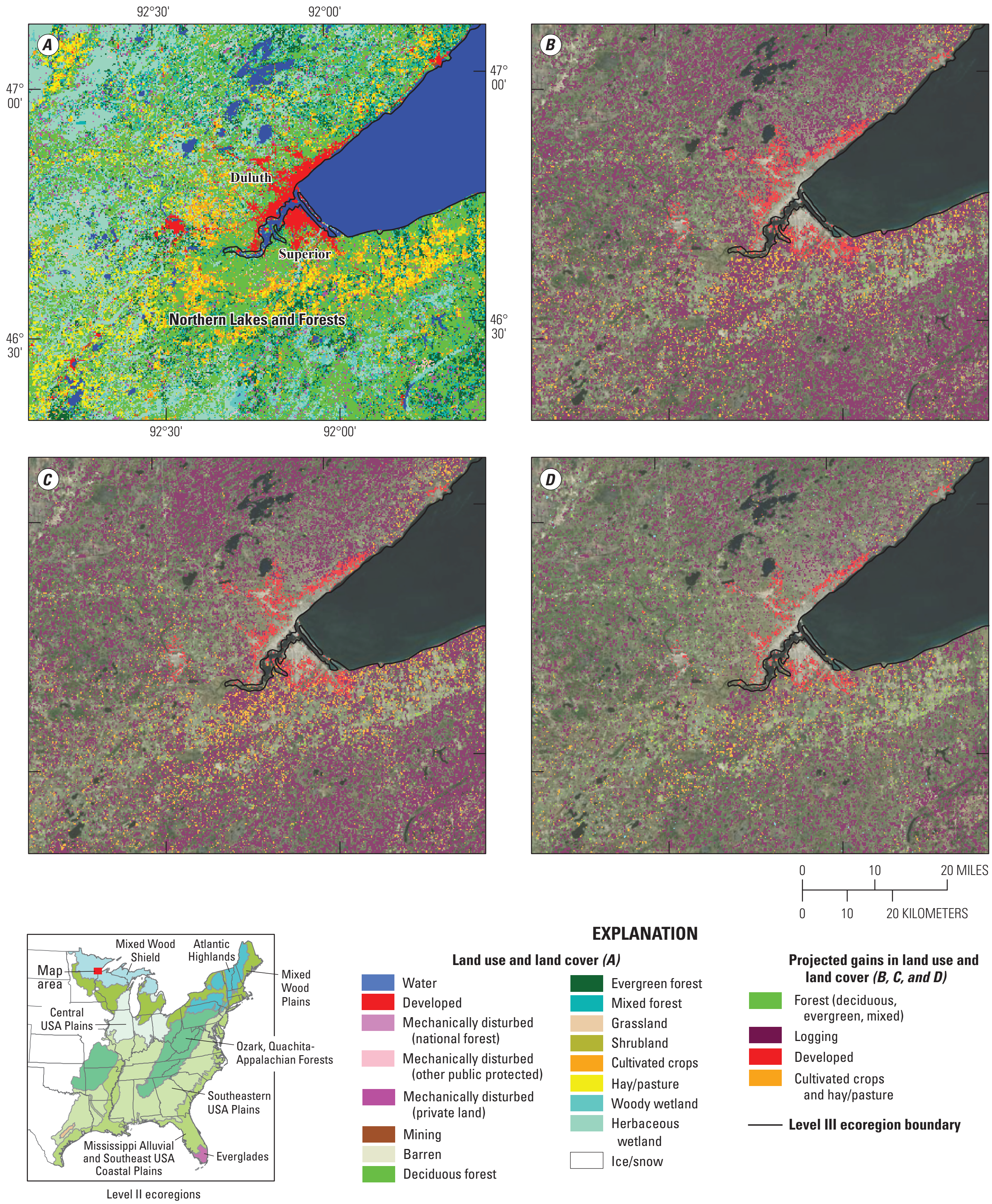


Figure 3–9. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, *C*, A2, and *D*, B1 in 2050 for the area around Duluth, Minnesota, in the Mixed Wood Shield ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.4.3.2. Atlantic Highlands

The LULC change footprint for each scenario in the Atlantic Highlands ecoregion was among the most extensive of the ecoregions in the Eastern United States during the projected time period. The two economically focused scenarios A1B and A2 had similar amounts of change with 22.9 percent of the ecoregion area changing at least once in scenario A1B and 22.1 percent changing in scenario A2 (table 3–3). In the environmentally oriented scenario B1, 14.2 percent of the ecoregion changed.

There was significant variation in the amount of LULC change projected between the three level III ecoregions that make up the Atlantic Highlands ecoregion. During the projected period, high amounts of change occurred in the Northern Appalachian and Atlantic Maritime Highlands and the North Central Appalachians level III ecoregions where large amounts of forest cutting and conversion to developed was common. Conversely, the Northern Appalachian Plateau and Uplands level III ecoregion experienced slight changes in LULC, largely because of the area's lack of clearcutting.

A majority of the change in the economically focused scenarios A1B and A2 was due to clearcutting activities in forests and increases in other anthropogenic land uses. Between 2006 and 2050, increases in forest harvest activities were dramatic. In scenario A1B, the extent of clearcutting increased by 541.9 percent (5,315 km^2), whereas in scenario A2, the extent of clearcutting increased by 492 percent (4,825 km^2). The increase in the extent of developed lands was substantial as well. In the A1B scenario, the extent of developed lands increased by 107.1 percent (3,625 km^2), whereas in scenario A2, the extent of developed lands increased by 42.5 percent (1,438 km^2). The extent of agricultural lands also expanded in scenario A2 (28.5 percent, 5,193 km^2) and to a lesser extent in scenario A1B. The extent of mining expanded in the two scenarios as well, increasing by 66.5 percent (158 km^2) in scenario A1B and by 91.1 percent (217 km^2) in scenario A2. In both scenarios, conversion from forests contributed to more than 90 percent of the gains seen by each of these anthropogenic LULC types.

In scenario B1, clearcutting activities and expansion of developed lands contributed the most to land changes that were observed for the projected period. The extents of clearcutting and developed lands were lower compared with those in the economic scenarios but still high overall. The extent of clearcutting of forested lands expanded by 204.5 percent (2,006 km^2), whereas the extent of developed lands increased by 25.1 percent (848 km^2). Most of the gains in developed were at the expense of forests (79.9 percent, 678 km^2); however, this did not result in an overall loss in forest cover. Scenario B1 was the only scenario to have an increase in the extent of the forests ecosystem, albeit a minor gain (1.2 percent, 1,895 km^2). This was mostly due to the large declines in the extent of agricultural lands (15.2 percent, 2,771 km^2) during the projected time period.

Figure 3–10 represents typical LULC patterns between scenarios. The expansion in all directions near and around the cities of Pittsfield and Springfield, Massachusetts, can clearly be discerned in all scenarios as the area's population increases. In this example, gains in the extent of developed lands are considerably less in scenario B1 where growth is more compact compared with the more sprawling scenarios A1B and A2. Agricultural lands expand considerably in scenarios A1B and A2, particularly in lowland valleys and adjacent to existing cultivated areas. In an attempt to accommodate the increased demand for agricultural products, agriculture stretches into the west and northeast to increasingly marginal lands. In scenario B1, agriculture LULC does expand slightly into new areas; however, agricultural lands are also being converted to other ecosystem classes, leading to an overall decrease in the extent of agricultural lands in this scenario. Between scenarios, the spatial distributions of clearcut forest are the same for this area. The density of clearcutting, however, varies between economic and environmental scenarios. In the economic scenarios, forest resources are in high demand with less of a focus on preservation and responsible forest use. Conversely, the environmental scenarios put a value on forest preservation and restoration, leading to lower amounts of clearcutting as well as increases in total forested area, particularly as the lower demand for agricultural commodities result in conversions of agricultural lands to forests ecosystems.

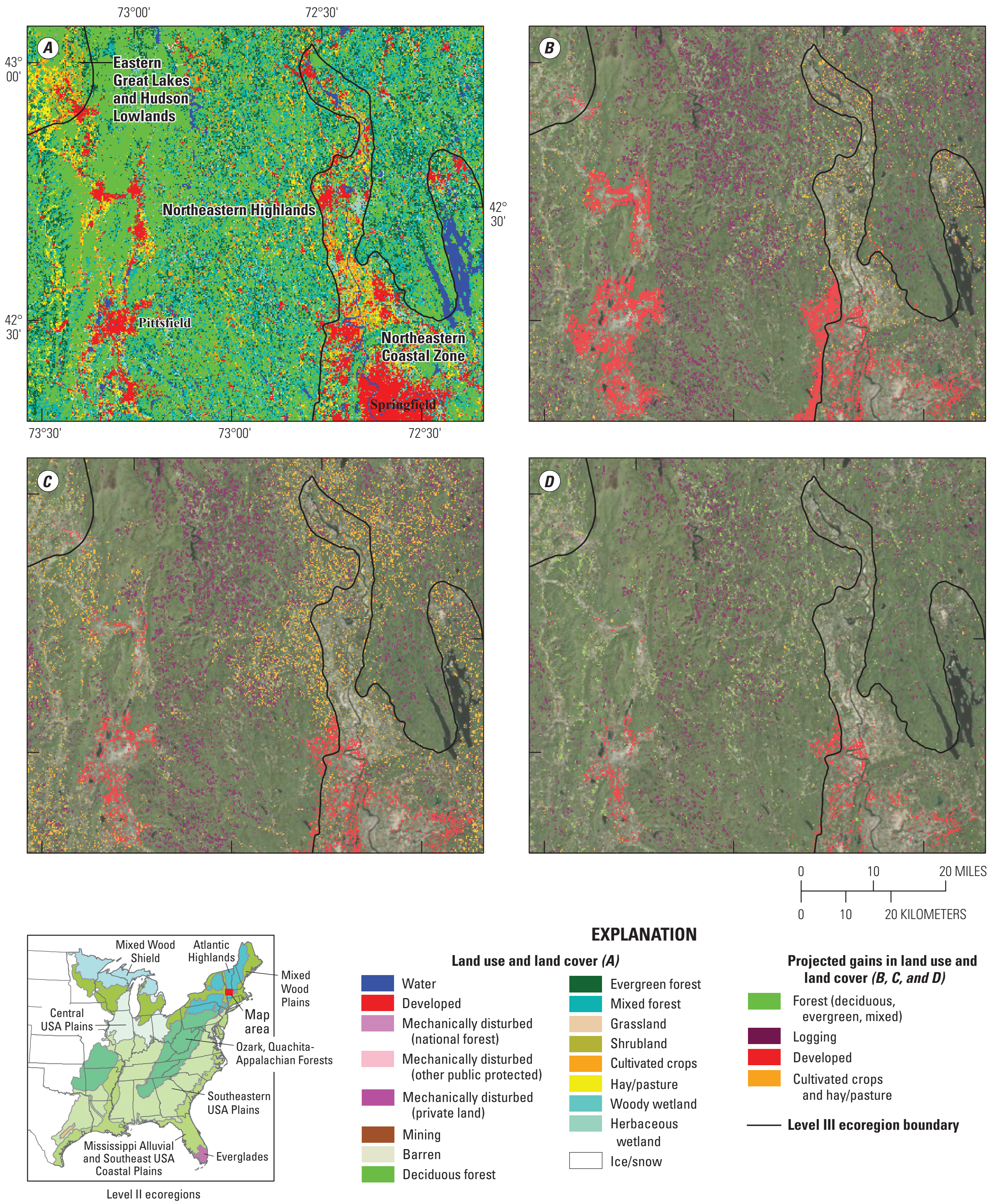


Figure 3–10. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, *C*, A2, and *D*, B1 in 2050 for the area near Springfield, Massachusetts, in the Atlantic Highlands ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.4.3.3. Mixed Wood Plains

Each of the scenarios for the Mixed Wood Plains ecoregion exhibited some of the lowest amounts of LULC change in the Eastern United States. By contrast to many other eastern ecoregions, the LULC change footprint in the Mixed Wood Plains ecoregion was greatest in the in scenario A2 rather than scenario A1B. In scenario A2, 13.9 percent of the ecoregion's LULC changed at least one time between 2006 and 2050, with scenario A1B similar at 13.1 percent (table 3–3). Scenario B1 had the least amount of LULC change, with only 7.3 percent.

There is spatial variability in the amount and types of LULC change across the ecoregion. For example, the Maine/New Brunswick Plains and Hills level III ecoregion continued the historical trend of having the highest amount of spatial change across all scenarios due to high amounts of forest cutting. The Driftless Area ecoregion in Wisconsin and Minnesota had the lowest amount of change in scenarios A1B and A2, but in the environmental scenario B1, this area had the second highest amount of change due to afforestation.

In both the economically focused scenarios, the extents of developed lands and forest clearcutting increased dramatically during the projected time period. In scenarios A1B and A2, the extents of developed lands increased by 47.1 percent (13,366 km^2) and 37.9 percent (10,764 km^2), respectively. Forests and agricultural lands combined to contribute more than 90 percent of the land converted to developed lands; however, the contributions of forest and agricultural lands to developed lands varied by scenario. In scenario A1B, 39.6 percent (5,293 km^2) of the land converted to developed lands came from forests, and 55.9 percent (7,472 km^2) came from agricultural lands, whereas in scenario A2, the trend was reversed. The variation in conversions reflects where new developed occurred. In scenario A1B, there was more development in agricultural areas in the western part of the ecoregion, whereas in scenario A2, the extent of developed lands grew more in the more forested eastern regions.

The economically focused scenarios saw increases in forest clearcutting of 279.1 percent (3,308 km^2) in scenario A1B and 249.3 percent (2,955 km^2) in scenario A2. Although forest harvest increased, the areal extent of the overall forest ecosystem decreased by 7.9 percent (11,747 km^2) in scenario A1B and 13.8 percent (20,430 km^2) in scenario A2 due to conversion to other LULC types. From 2006 through 2050, the extent of agricultural lands in scenario A1B experienced a small net loss of less than 200 km^2, with losses occurring to developed lands but gains coming from forests. Scenario A2 saw a 6.6 percent (10,533 km^2) increase in the extent of agricultural lands, predominantly from forests.

The environmental scenario B1 had the smallest increase in the extent of developed lands at 29 percent (8,239 km^2). Conversions to developed lands were similar to scenario A1B where more agricultural lands (60 percent, 4,943 km^2) were converted than forests (36.4 percent, 2,999 km^2). The extent of the forests ecosystem in scenario B1 changed little, but forest clearcutting did increase by nearly 20 percent. Finally, agricultural lands saw a decrease of 5.3 percent (8,463 km^2) during the projected time period due to conversions to developed lands and forests

Figure 3–11 illustrates typical projected LULC change in the Bangor, Maine, area between 2006 and 2050. In all scenarios, developed lands expanded into the agricultural lands and forested areas around the city, but to a lesser degree in scenario B1 than in scenarios A1B and A2. A drastic increase in the amount of forest clearcutting can be seen throughout the surrounding area in the economically focused scenarios. Conversely, the expansion of forest cutting in scenario B1 was more moderate than in scenarios A1B and A2, and small patches of new forested land can be observed. The economic scenarios also showed a large gain in the amount of agricultural lands, which helped offset losses to developed areas. However, in scenario B1, gains in the extent of agricultural LULC are much smaller, and losses to developed lands result in an overall decrease in the extent of agricultural lands in the area between 2006 and 2050.

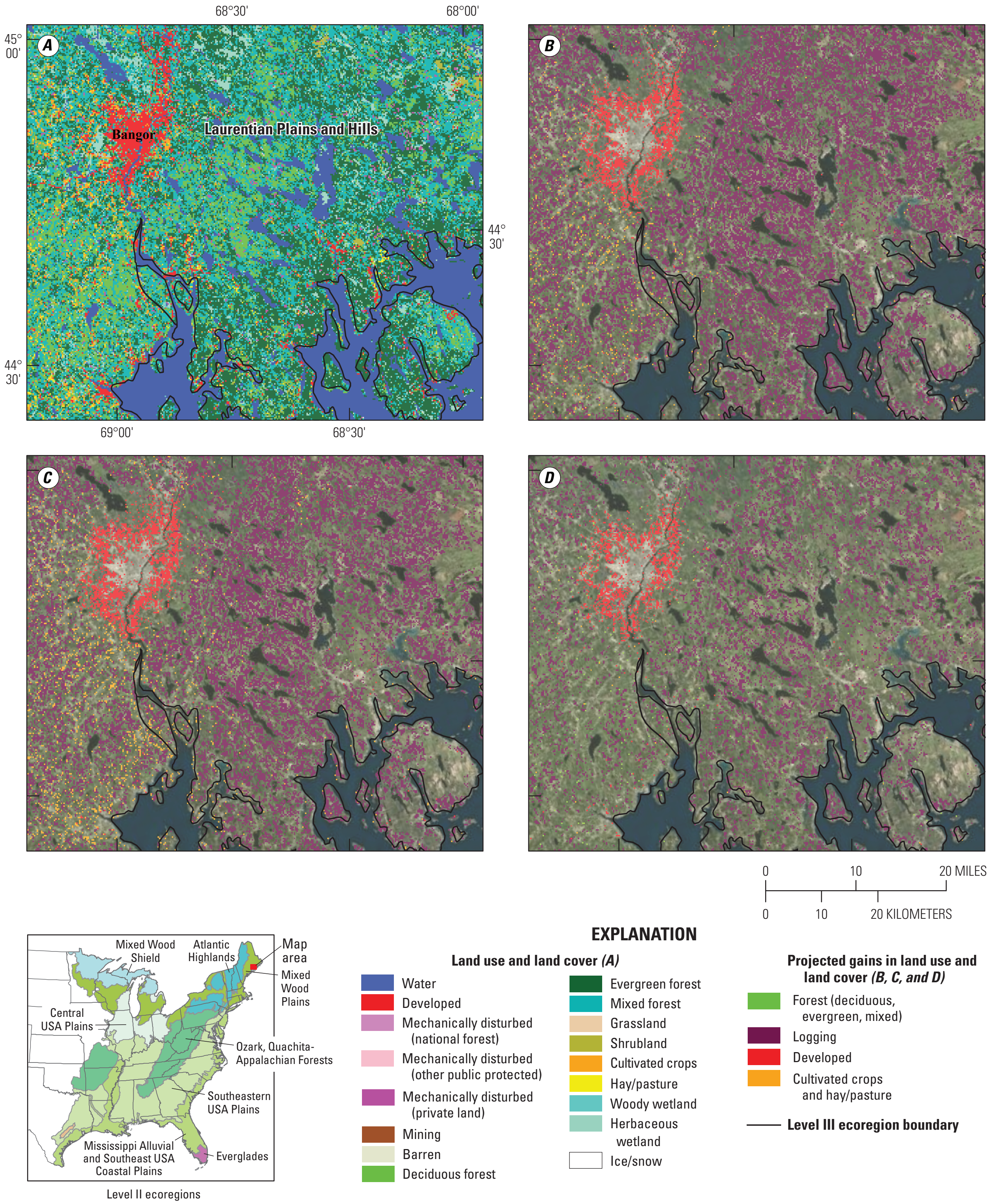


Figure 3–11. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, *C*, A2, and *D*, B1 in 2050 for the area around Bangor, Maine, in the Mixed Wood Plains ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.4.3.4. Central USA Plains

The Central USA Plains ecoregion was the least active ecoregion in the Eastern United States in terms of LULC change, with LULC change footprints in each scenario the lowest of the entire Eastern United States. With little existing forest, there are only small amounts of clearcutting to contribute to LULC change, and much of the area has stabilized as a highly productive agricultural region. Scenario B1 had the least amount of LULC change in the Central USA Plains ecoregion with only 4.6 percent of the ecoregion changing at least once between 2006 and 2050 (table 3–3). Scenario A2 saw 7.5 percent of the ecoregion change at least once, and scenario A1B saw 9.3 percent of the ecoregion change at least once. The spatial variability of LULC change across the ecoregion was low. Between level III ecoregions in the Central USA Plains, variability in footprint change did not exceed 4 percent.

The economically focused scenarios saw considerable increases in the extents of developed lands and decreases in the extents of agricultural lands and forests. In scenario A1B, the extent of developed lands increased by 80.1 percent (14,757 km^2), whereas scenario A2 saw an increase of 55.8 percent (10,275 km^2). In both economic scenarios, gains in the extent of developed lands came primarily from the conversion of agricultural lands. Despite these conversions, agricultural lands retained almost 90 percent of the extent in 2005 during the projected time period, experiencing only small net decreases of 6.1 percent (11,214 km^2) in scenario A1B and 3.6 percent (6,759 km^2) in scenario A2. Natural ecosystems saw reductions in their extent as well, with forests declining by similar amounts (13.9 percent, 3,316 km in scenario A1B and 13.9 percent, 3,311 km^2 in scenario A2).

In scenario B1, increases in the extent of developed lands were modest compared with those in scenarios A1B and A2. The extent of developed lands increased by 24.2 percent (4,458 km^2) between 2006 and 2050, with most of the increase coming from agricultural lands (86 percent, 3,834 km^2). Similar to the economically focused scenarios, the extent of agricultural lands experienced a net decrease (2.5 percent, 4,712 km^2) in scenario B1, but this decrease was smaller than that in the other two scenarios due to scenario assumptions limiting expansion of developed lands. The extent of the forests ecosystem saw a slight increase of less than 1 percent. Types of LULC change in the Chicago, Illinois, area are typical of the changes in the Central USA Plains from 2006 through 2050. In all scenarios, developed lands expanded into agricultural lands along the fringes of the metropolitan areas (fig. 3–12). In scenarios A1B and A2, development was more apt to occur in the remaining forested areas within the city. However, in scenario B1, development was more compact and, coupled with an increased focus on preserving natural cover types, kept developed lands from encroaching as much into the city's forested areas.

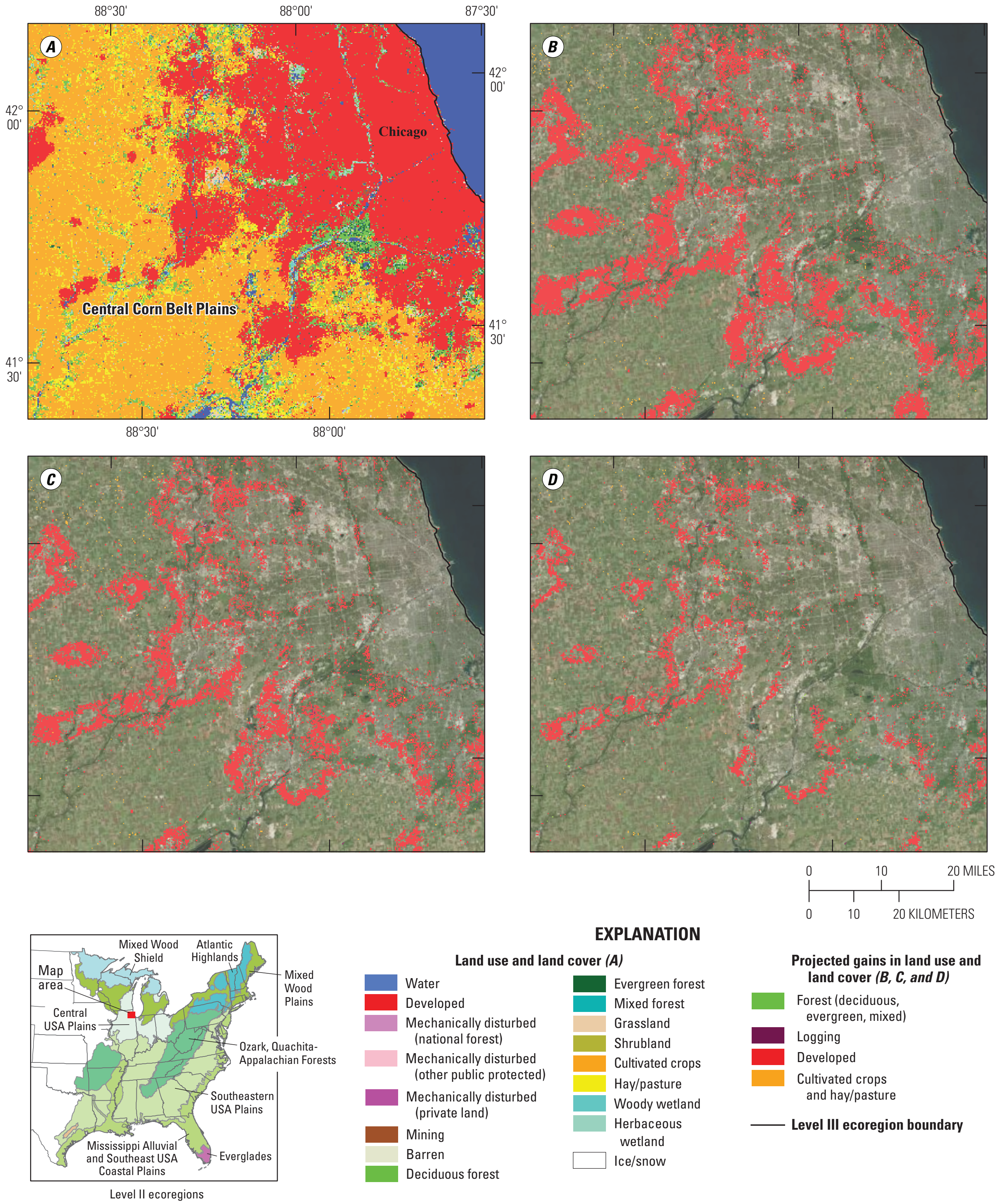


Figure 3–12. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, *C*, A2, and *D*, B1 in 2050 for the area around Chicago, Illinois, in the Central USA Plains ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.4.3.5. Southeastern USA Plains

The Southeastern USA Plains ecoregion continued the recent historical trend of being the highest changing level II ecoregion in the Eastern United States in every scenario due to high rates of clearcutting and LULC conversions. The ecoregion is very dynamic and had the largest LULC change footprints in the Eastern United States, with 33.2 percent in scenario A1B, 30.6 percent in scenario B1, and 29.5 percent in scenario A2 (table 3–3). Within the heart of the Southeastern USA Plains, the LULC change footprint exceeded 40 percent in the South Central Plains, Piedmont, Southeastern Plains, and Mississippi Valley Loess Plains level III ecoregions.

In both the economically focused scenarios, change was driven by high amounts of anthropogenic land uses in the form of forest clearcutting, developed lands, and agriculture. The ecoregion accounted for more than half (55.5 percent) of all forest clearcutting in the Eastern United States at the start of the projection period, and in both scenarios, clearcutting maintained an approximately 50 percent share in 2050. The extent of forest cutting increased by 34.6 percent (9,614 km^2) over the projection period in scenario A1B, which was a modest rate increase with the ecoregion being heavily harvested already. In addition to the increases in forest cutting, the extent of the forest ecosystem decreased by 13.8 percent (75,816 km^2), putting further conversion pressure on the region's forests. In scenario A2, forest clearcutting increased by 24.2 percent (6,724 km^2), and the extent of the overall forests ecosystem decreased by 12.4 percent (68,367 km^2).

In scenario A1B, the developed LULC class had the highest rate of increase across all ecoregions and scenarios with a 92.9 percent (39,946 km^2) gain. Conversions to developed lands in scenario A1B primarily came from forests (59.6 percent, 23,808 km^2) and agricultural lands (35 percent, 13,981 km^2). Scenario A2 experienced a 76.4 percent (32,848 km^2) increase in the extent of developed lands, with a greater percentage of new developed lands coming from forests (67.3 percent, 22,107 km^2) than in scenario A1B and a smaller share (26.1 percent, 8,573 km^2) from agricultural lands. Increases in the extent of developed lands were primarily concentrated in level III ecoregions with high LULC change footprints and in existing large urban corridors, with the Piedmont and Southeastern Plains level III ecoregions accounting for approximately 65 percent of all urban growth in both economic scenarios. In the Piedmont, the urban corridor stretching from Atlanta, Georgia; Washington, D.C.; Charlotte, Winston-Salem, and Raleigh-Durham, North Carolina, saw the greatest increases with 119.7 percent (14,480 km^2) in scenario A1B and 103.2 percent (12,484 km^2) in scenario A2. Developed lands in the Southeastern Plains level III ecoregion focused in cities along the edge of the Piedmont from Montgomery, Alabama; Macon, Ga.; Colombia, South Carolina; and Richmond, Virginia; to the southeastern fringes of Baltimore, Maryland, with increases of 92.7 percent (8,969 km^2) in scenario A1B and 80.8 percent (7,821 km^2) in scenario A2.

Gains in the extent of the agricultural lands ecosystem were also the largest by area in scenarios A1B and A2 compared with changes in the other level II ecoregions in the Eastern United States. The extent of agricultural lands increased by 11.7 percent (35,828 km^2) in scenario A1B and 11 percent (33,810 km^2) in scenario A2, with gains in both scenarios predominantly coming from forests and to a lesser degree from grasslands/shrublands.

Scenario B1 had the second highest LULC change footprint in this ecoregion due to continued high amounts of forest cutting, growth in developed lands, and restoration of forests and wetlands ecosystems. Forest cutting continued to increase (7.9 percent, 2,200 km^2), although at a rate much lower than scenarios A1B and A2. This increase is a deviation from much of the Eastern United States in scenario B1 where timber harvest generally decreased in the Eastern United States under this scenario. As a result of conversion of agricultural lands to forest, the overall extent of the forests ecosystem increased by 2.9 percent (15,829 km^2) during the projection period. The increases in the extent of developed lands (66 percent, 28,387 km^2) remained the highest of any ecoregion in the Eastern United States, but was still lower than either of the economic scenarios. New developed lands came more from agricultural lands (53.1 percent, 15,074 km^2) than from forests (42.4 percent 12,036 km^2) in scenario B1, with similar patterns of new urban growth as the economic scenarios except for a greater share of increases in the extent of developed lands in cities of the Interior Plateau and Interior River Valleys and Hills level III ecoregions, such as St. Louis, Missouri; Nashville, Tennessee; and Louisville, Kentucky. The extent of the wetlands ecosystem experienced a 7.8 percent (4,722 km^2) increase in scenario B1, with conversions to wetlands types predominantly from agricultural lands (67.7 percent, 3,197 km^2) and forests (30.6 percent, 1,445 km^2).

LULC change in the Augusta, Ga., region that borders the Piedmont and Southeastern Plains level III ecoregions is typical of the Southeastern USA Plains (fig. 3–13). Increases in the extent of developed lands from forested areas around Augusta were similar in the A1B and A2 scenarios; however, increases in the extent of developed lands were much lower in scenario B1, which has assumptions that focus more on compact urban growth. Higher rates of forest clearcutting and conversion to new agricultural lands are apparent in scenario A1B, with the higher densities of new agriculture visible in the areas northwest and southwest of Augusta. In scenario B1, forest restoration is noticeable in the cropped areas south of Augusta and in isolated patches in the western portion of the image. Use of the Protected Area Database of the United States in the LULC modeling is also apparent as seen near Fort Gordon, Ga., on the outskirts of Augusta. Anthropogenic LULC change is restricted on military lands in all scenarios as illustrated by the lack of new agricultural lands, forest clearcutting, and developed lands on base. However, conversions to natural LULC types such as forest and wetland are allowed in scenario B1 as seen by the new patches of forest in the center of the base.

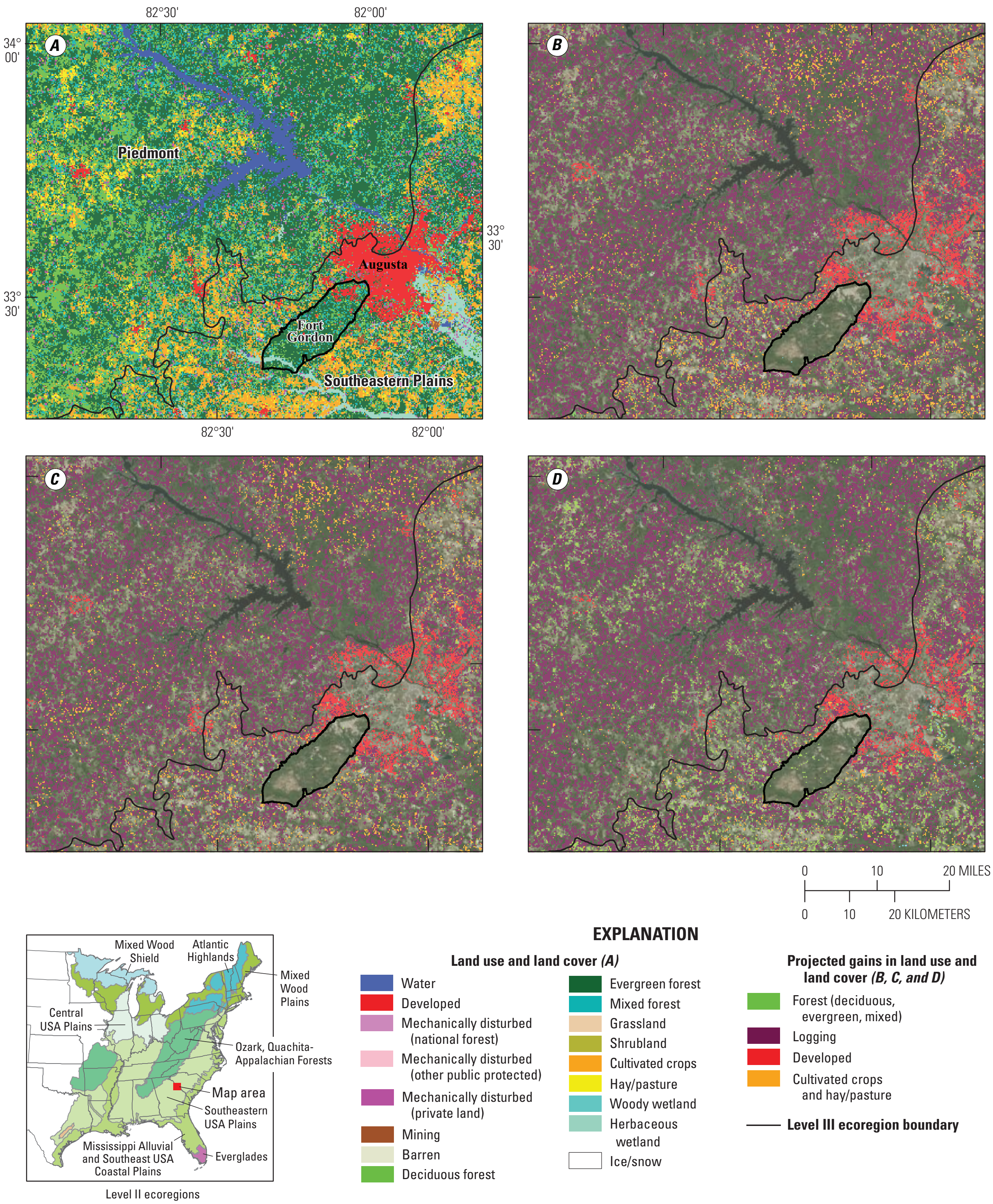


Figure 3–13. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, *C*, A2, and *D*, B1 in 2050 for the area around Augusta, Georgia, in the Southeastern USA Plains ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.4.3.6. Ozark, Ouachita-Appalachian Forests

The LULC change footprint in the Ozark, Ouachita-Appalachian Forests ecoregion closely resembles the average pattern for the Eastern United States during the projection period, especially in the economic scenarios. The A1B and A2 scenarios had change rates of 20.5 percent and 19.7 percent, respectively, compared with the Eastern United States with 22.9 percent in scenario A1B and 20.8 percent in scenario A2 (table 3–3). However, the rate of LULC change in scenario B1 was considerably lower (10.6 percent) than the Eastern United States average (17.2 percent). However, several level III ecoregions were noticeable exceptions to the trend in the ecoregion, with the Southwestern Appalachians and Ouachita Mountains level III ecoregions showing a rate of LULC change of about 40 percent or more due to the high amounts of forest clearcutting in these areas. The Ouachita Mountains ecoregion in particular had the highest rate of any level III ecoregion in the entire Eastern United States, with nearly half of the area changing at least once during the projection period in every scenario (48.1 percent in scenario A1, 55.4 percent in scenario A2, and 44.7 percent in scenario B1; fig. 3–5).

In both the economically focused scenarios, LULC change was driven primarily by forest clearcutting, moderate growth in major urban centers, and agricultural expansion in the Ozark Highlands ecoregion and the lowland valleys of the Appalachian Mountains. Forest clearcutting in scenario A1B increased by 162.2 percent (9,129 km^2) and 145.5 percent (7,426 km^2) in scenario A2 during the projected period, an increase three times that of the Eastern United States averages of 49.2 percent (24,593 km^2) in scenario A1B and 38 percent (18,978 km^2) in scenario A2. The extent of the forests ecosystem decreased by 7.2 percent (26,898 km^2) in scenario A1B and 8.2 percent (30,599 km^2) in scenario A2 due to conversions to agricultural and developed lands. Both scenarios saw increases in the extent of the developed agricultural lands, with the extent of developed lands increasing by 67.1 percent (9,129 km^2) primarily from forests (67.6 percent, 6,171 km^2) compared with agricultural lands (29.9 percent, 2,730 km^2) in scenario A1B. In scenario A2, the extent of developed lands increased by 54.6 percent (7,426 km^2), with a greater proportion of new urban lands coming from forests (77.7 percent, 5,770 km^2) than agricultural lands (19.9 percent, 1,478 km^2). Compared with developed lands, increases in agricultural lands were higher in scenario A2 (19.1 percent, 22,520 km^2) than in scenario A1B (14.8 percent, 17,425 km^2), with almost all new agricultural lands converted from forests.

Scenario B1 saw few net changes in the ecoregion with the extents of forest, agriculture, and forest clearcutting LULC all remaining relatively stable throughout the projection period. The extent of developed lands saw a moderate increase of 31.1 percent (4,229 km^2) for the largest scenario change. Gains in developed lands were balanced between forests (56.2 percent, 2,377 km^2) and agricultural lands (40.2 percent, 1,700 km^2). Forest clearcutting was considerably lower in scenario B1 compared with the economically oriented scenarios but did increase slightly by a little more than 3 percent during the projection period, in contrast with the Eastern United States as a whole, which saw clearcutting decrease by 6.9 percent (3,430 km^2). The extent of the forests ecosystem decreased overall by 0.8 percent (2,991 km^2) due primarily to conversions to new urban growth. Decreases in agricultural lands were minimal.

LULC change in the Birmingham, Alabama, area is indicative of changes in the region (fig. 3–14), with high amounts of forest clearcutting seen in scenarios A1B and A2 and less so in scenario B1. Growth of large cities such as Birmingham is similar between scenarios A1B and A2, with slightly higher increases in scenario A1B. Smaller cities such as Jasper, Ala., follow similar growth patterns as the larger towns, whereas increases in the extent of developed lands are much lower in metropolitan and rural areas in scenario B1. Conversions of forests to agricultural lands are highest in scenario A2, with greater concentrations of new agricultural lands northwest and southwest of Birmingham. Increases in agricultural lands are slightly lower in scenario A1B, following similar patterns as scenario A2. Widespread forest restoration is visible throughout scenario B1, as isolated patches of agricultural lands are converted to forests.

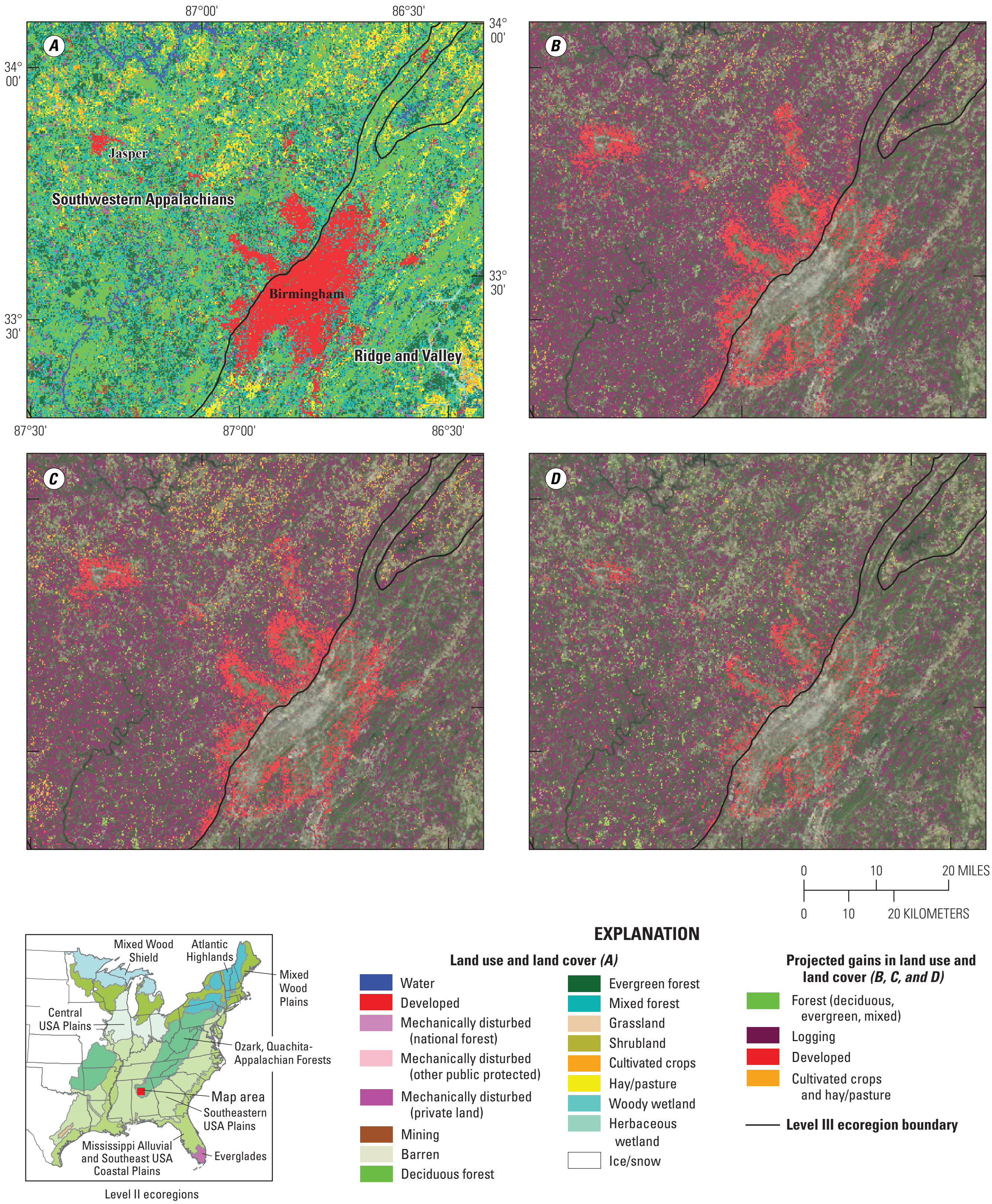


Figure 3–14. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, C, A2, and *D*, B1 in 2050 for the area Birmingham, Alabama, in the Ozark, Ouachita-Appalachian Forests ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.4.3.7. Mississippi Alluvial and Southeast USA Coastal Plains

From 2006 through 2050, the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion experienced modest amounts LULC change in each scenario. Scenario A1B had the greatest amount of LULC change with 16.1 percent of the ecoregion changing at least once during the projected period (table 3–3). Scenario B1 experienced the second largest LULC change with 13.9 percent and scenario A2 was a close third with 13.1 percent. The amount of LULC change varied spatially by level III ecoregions within the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion. As in the baseline results, the Southern Coastal Plain ecoregion in the southeastern part of the ecoregion saw large amounts of LULC change in all scenarios. The Middle Atlantic Coastal Plain and the Western Gulf Coastal Plain (of the Texas-Louisiana Coastal Plains level III ecoregion) ecoregions saw comparatively modest amounts of change, whereas the Atlantic Coastal Pine Barrens and the Mississippi Alluvial Plain ecoregions saw relatively little change (fig. 3–5).

The economically focused scenarios experienced drastic increases in the extent of developed lands and substantial decreases in the extents of natural ecosystems (forests, wetlands, and grasslands/shrublands) during the projected time period. In scenario A1B, the extent of developed lands increased by 84.1 percent (28,872 km^2), most of which came from agricultural lands (38.3 percent, 11,058 km^2), forests (35.1 percent, 10,134 km^2), and wetlands (16.6 percent, 4,793 km^2). The extent of developed lands in scenario A2 saw a 69.6 percent (23,891 km^2) increase, with a greater share of conversions from forests in this scenario (40.4 percent, 4,793 km^2) and relatively equal amounts from agricultural lands (23.7 percent, 5,662 km^2) and wetlands (22.8 percent, 5,447 km^2).

In scenarios A1B and A2, the extent of the forests ecosystem saw decreases of 21.5 percent (21,919 km^2) and 15.9 percent (16,258 km^2) respectively. However, forest clearcuts increased by 54.9 percent (5,412 km^2) in scenario A1B and by 58.4 percent (5,758 km^2) in scenario A2 in a decreasing forested land base. The extent of the wetlands ecosystem also decreased, by 7.2 percent (8,403 km^2) in scenario A1B and by 6 percent (7,018 km^2) in scenario A2. The Mississippi Alluvial and Southeast USA Coastal Plains ecoregion was one of the few areas of the Eastern United States that had substantial amounts of the grasslands/shrublands ecosystem, which decreased by 7.5 percent (2,142 km^2) in scenario A1B and 8.7 percent (2,490 km^2) in scenario A2. Conversions from these natural ecosystems were primarily to developed and agricultural lands, which also saw slight increases of 2.2 percent (3,106 km^2) in scenario A1B and 0.9 percent (1,327 km^2) in scenario A2.

In scenario B1, the extent of developed lands continued to grow, with a 43.6 percent (14, 959 km^2) increase being the second highest in the Eastern United States (scenario B1), which came primarily from agricultural lands (43.6 percent, 6,522 km^2), forests (37.5 percent, 5,610 km^2), and grasslands/shrublands (9.1 percent, 1,361 km^2). Forests and grassland/shrublands ecosystems continued to experience net declines in scenario B1, with the extents of forests decreasing by 5.1 percent (5,173 km^2) and grasslands/shrublands by almost 3 percent. Forest clearcutting decreases were the greatest across the entire Eastern United States, with a decrease of 53.8 percent (5,305 km^2) during the projection period. The wetlands ecosystem, contrary to the economic scenarios, experienced a net increase of 5.1 percent (5,985 km^2), with conversions to wetlands almost exclusively from agricultural lands. Agricultural lands experienced a net loss of 11.2 percent (16,067 km^2) to developed lands and wetlands.

LULC changes in the Jacksonville, Florida, area are representative of the variety of changes that took place in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion. The extent of developed lands in scenarios A1B and A2 showed similar patterns of expansion into the forests and wetlands surrounding Jacksonville, whereas increases in developed lands in scenario B1 were much lower (fig. 3–15). Other developed lands expanded to the south of Camp Blanding, Fla., and came from forests, agricultural lands, and wetlands. Gains in agriculture are greatest in scenario A1B and can be seen expanding into the forest lands north of Camp Blanding. In scenario B1, agricultural losses to forested lands can be seen in several areas. Both Camp Blanding and Okefenokee Swamp were protected under all scenarios and thus growth was restricted in those places.

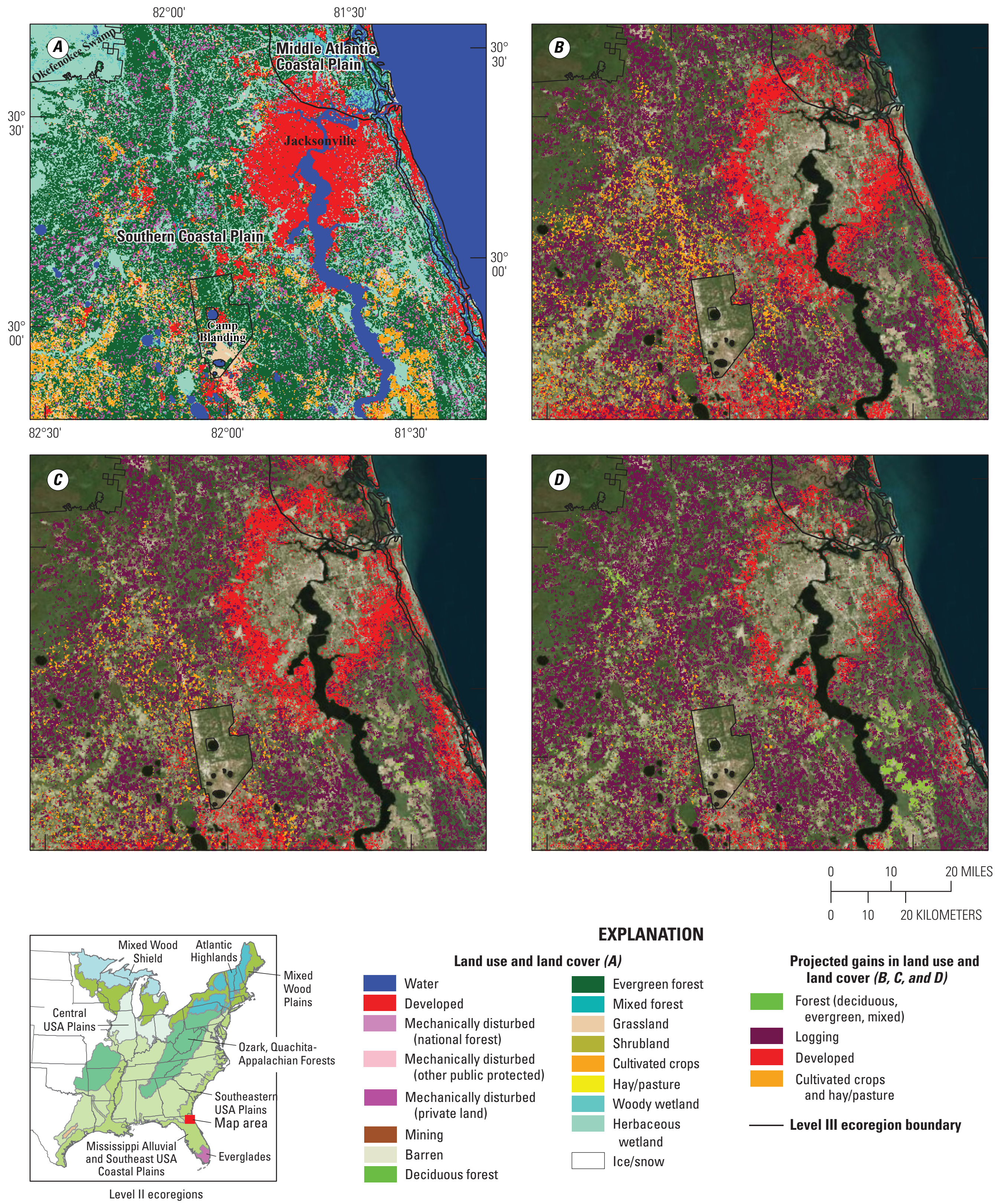


Figure 3–15. Maps showing *A*, land use and land cover (LULC) and a comparison of the projected LULC change in scenarios *B*, A1B, *C*, A2, and *D*, B1 in 2050 for the area around Jacksonville, Florida, in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion. Changes were projected to be the result of land-use change (agricultural lands, forests, developed lands) or forest clearcutting.

3.5. Validation and Uncertainty

3.5.1. Baseline Validation and Uncertainty

For a historical period, a formal, quantitative validation of the 1992 through 2005 LULC maps is theoretically possible. Quantitative validation of LULC model output typically examines measurements of quantitative disagreement to ensure that the model produced the correct LULC quantities over a study area and allocation disagreement to ensure that the model place LULC change in the correct locations (Pontius and Millones, 2012). The quantity of mapped LULC change for the baseline period was informed and calibrated by data derived from the USGS Land Cover Trends Project for 1992 through 2000 and by the NLCD2006 land cover change product for LULC change from 2001 through 2005. The FORE–SCE model has the ability to precisely match prescribed proportions of LULC change and thus replicate the historical amounts of LULC change provided by the two datasets. Quantitative disagreement was therefore not an issue, because model runs were rejected if FORE–SCE could not accurately replicate the prescribed quantities of LULC change for any reason.

Conversely, allocation disagreement is potentially subject to validation. Given that all level III ecoregions were parameterized and modeled independently, allocation disagreement was partially mitigated because the proportions of LULC change were spatially distributed to the appropriate ecoregion. Allocation disagreement was thus only an issue within a level III ecoregion. Forest clearcuts were not modeled, but were mapped using the LANDFIRE VCT data. All other types of LULC change were modeled by FORE–SCE and were subject to allocation disagreement assessment. However, there were difficulties in assessing allocation disagreement using USGS trends and NLCD data. The USGS trends data are sample based, limiting our ability to make spatial comparisons with the wall-to-wall maps. The starting 1992 NLCD used a different classification scheme and mapping methodology than the 2001 NLCD, and the two datasets cannot be directly compared to determine change between 1992 and 2001. A retrofit product of LULC change between 1992 and 2001 was produced for NLCD, remapping the 1992 NLCD using 2001 methodologies; the retrofitted 1992 data represent a different product than the 1992 NLCD used for this work. The 2001 and 2006 NLCD data were produced using a consistent methodology and theoretically could be used to evaluate the allocation disagreement of the modeled LULC change for that period. However, the 2001 and 2006 NLCD products are not directly comparable to the starting 1992 NLCD, again making direct comparison with the modeled 2001 through 2006 maps of little use.

There is no single standardized methodology for judging all LULC models (Rykiel, 1996), and quantitative validation cannot serve as the sole basis for judging a model to be valid or invalid (Verburg and others, 2006). Given the lack of quantitative disagreement (with FORE–SCE matching prescribed LULC proportions), model assessment boils down to the question of whether LULC change is being placed in suitable locations. With quantitative validation difficult due to characteristics of the available historical LULC data, model assessment thus focused on qualitative assessment of model input parameters controlling suitability of the land to support a given LULC type and of model results. Suitability surfaces were constructed for each LULC class in every level III ecoregion of the Eastern United States, each serving to control the location of LULC change. For each and every suitability surface, the quality of the surface and the fidelity of the regressions used to create those surfaces were reviewed. Suitability surfaces with perceived statistical or representational issues were recreated and subject to further review. A similar qualitative assessment was used to judge final model performance. During the modeling process, the performance of the model from 1992 through 2005 was evaluated independently for each level III ecoregion using a visual assessment of the LULC change distribution. The assessment was based on historical and current patterns of change, LULC patch size characteristics, spatial arrangement and context, and dispersion patterns. An unacceptable distribution of LULC change resulted in a reparameterization of the FORE–SCE model, and a subsequent new model run was initiated, with the process repeating until model performance was deemed acceptable.

3.5.2. Projected Validation and Uncertainty

A formal validation of the projected LULC changes was not possible because there were no reference data for a future timeframe. Although a validation cannot be performed for the projected period, sources of uncertainty may be examined in the projections for the future. There are many sources of uncertainty for LULC projections into the future and may include data sources, modeling assumptions regarding future driving forces, misrepresentation of processes within the model, incomplete knowledge and unknowns, and uncertainty propagation between model components (Dendocker and others, 2008; Verburg and others, 2012). Sensitivity analyses on the effects of individual contributors to overall uncertainty have been performed by land cover modelers, but accounting for all sources of uncertainty and how they propagate through a LULC modeling framework remains a daunting challenge.

For this assessment, the proportions of the projected LULC change in the scenarios themselves were used to bound overall uncertainties regarding future LULC proportions. Although not all sources of uncertainty that contribute to the final maps of projected LULC could be quantitatively assessed, the same quantity and allocation disagreement measurements discussed previously may be used to examine sources of uncertainty between the modeled scenarios. In this context, a quantitative disagreement measurement can be used to examine the differences in projected LULC proportions between scenarios. The spatial modeling component of FORE–SCE introduced allocation disagreement between scenarios in that the spatial pattern of change at a pixel level may differ between two scenarios even if the prescribed scenario LULC proportions were similar. Applications of quantitative and allocation disagreement measurements to each pair of the three scenarios allowed for a determination of whether the per-pixel differences between scenarios maps were because of the scenario LULC prescriptions themselves or were a result of the spatial modeling and the placement of LULC change (Sohl and others, 2012a).

Total disagreement, the per-pixel measurement of differences between paired scenario images, was relatively similar between each scenario pair, topping out at around 14 percent by 2050 (fig. 3–16). However, the contributions of quantitative disagreement and allocation disagreement differ between scenario pairs. Even by 2050, the prescribed proportions of LULC change, as provided by scenarios A1B and A2, are quite similar, because quantitative disagreement is quite low. Most of the per-pixel differences between scenarios A1B and A2 are due to exact placement of change from the spatial allocation model, and not from prescribed scenario differences. Given the similarity between scenarios A1B and A2, results of comparisons of those scenarios to scenario B1 are quite similar. The comparisons between scenarios A1B and B1 and between scenarios A2 and B1 show significant levels of quantitative disagreement, with quantitative disagreement reaching similar levels as allocation disagreement by 2050. This is a similar pattern to past FORE–SCE model runs with per-pixel differences in the placement of LULC change outweighing differences early in simulations due to the scenarios themselves, but with scenario differences becoming increasingly important as the model iterates forward in time (Sohl and others, 2012a). Although this assessment only analyzed change through 2050, LULC model runs were completed through 2100. In all scenario pairs, quantitative disagreement significantly increases after 2050, including in the A1B and A2 scenario pair, suggesting that in this modeling framework, long simulation periods are most effective for evaluating prescribed scenario differences. It should be noted, however, that allocation disagreement measures are calculated at the pixel level, and allocation disagreement will be measured even if LULC change is placed in very close proximity between two scenarios. Given the emphasis that FORE–SCE places on LULC change in suitable locations for a given LULC type, it is not expected that per-pixel differences between exact placement of LULC change patches would result in significant differences in reported carbon and GHG fluxes in this assessment, although future sensitivity analyses may be needed to confirm this.

Differences between scenarios can also be examined spatially to identify areas where future LULC is more certain (for example, same LULC type regardless of future modeled scenario) or more uncertain (for example, different LULC type due to either scenario or spatial allocation of LULC change). The spatial diversity image (fig. 3–17) indicates where the three scenarios are the same in 2050 and where they are different, at the pixel level. When examining differences between the three scenarios for 2050, 19.7 percent of all pixels for the Eastern United States are different between two or more scenarios, whereas 80.3 percent are the same between all scenarios. The scenarios are clearly the most different in forested ecoregions of the Southeast. Levels of forest clear-cutting differ between the scenarios, and scenario differences clearly show up in the forested ecoregions of the Southeastern United States with high levels of timber activity. Quantitative disagreement (scenario differences) undoubtedly contributes to much of the per-pixel diversity, but allocation disagreement (pixel-level differences of where LULC change patches are placed) is also an important factor in differences between modeled scenarios (fig. 3–17). Forested regions with low amounts of cutting, such as those in the Northeast and upper Midwest, show lower diversity between scenarios than do the ecoregions in the Southeast. Scenarios are the most similar in heavily agricultural ecoregions, such as in the Corn Belt of the Midwest and the Mississippi Alluvial Valley.

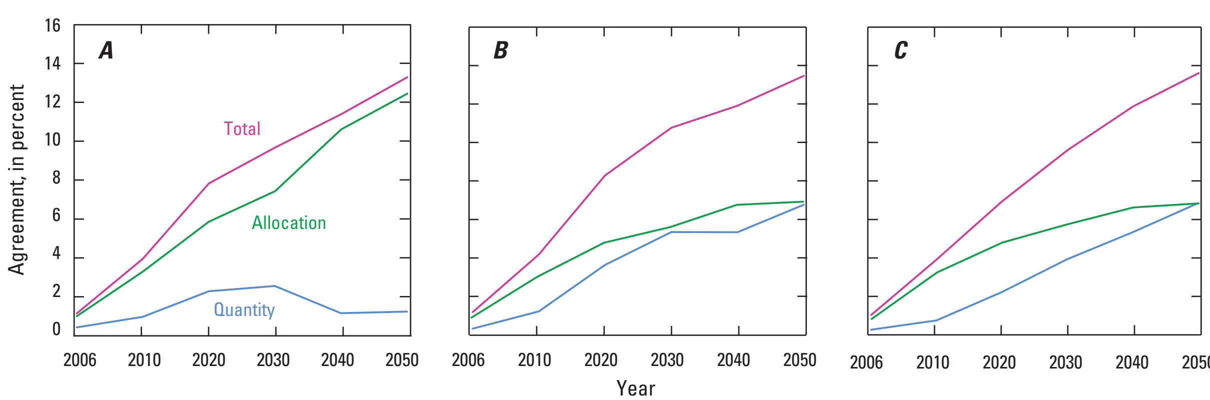


Figure 3–16. Graphs showing comparisons of quantity and allocation disagreement for land-use and land-cover scenarios (Nakićenović and others, 2000) *A*, A1B and A2, *B*, A2 and B1, and *C*, A1B and B1 for the Eastern United States from 2006 through 2050. The total disagreement between scenario pairs is relatively similar for the three scenario pairs. However, scenarios A1B and A2 are clearly similar through 2050, with allocation disagreement making up most of the disagreement between scenarios A1B and A2 even by 2050.

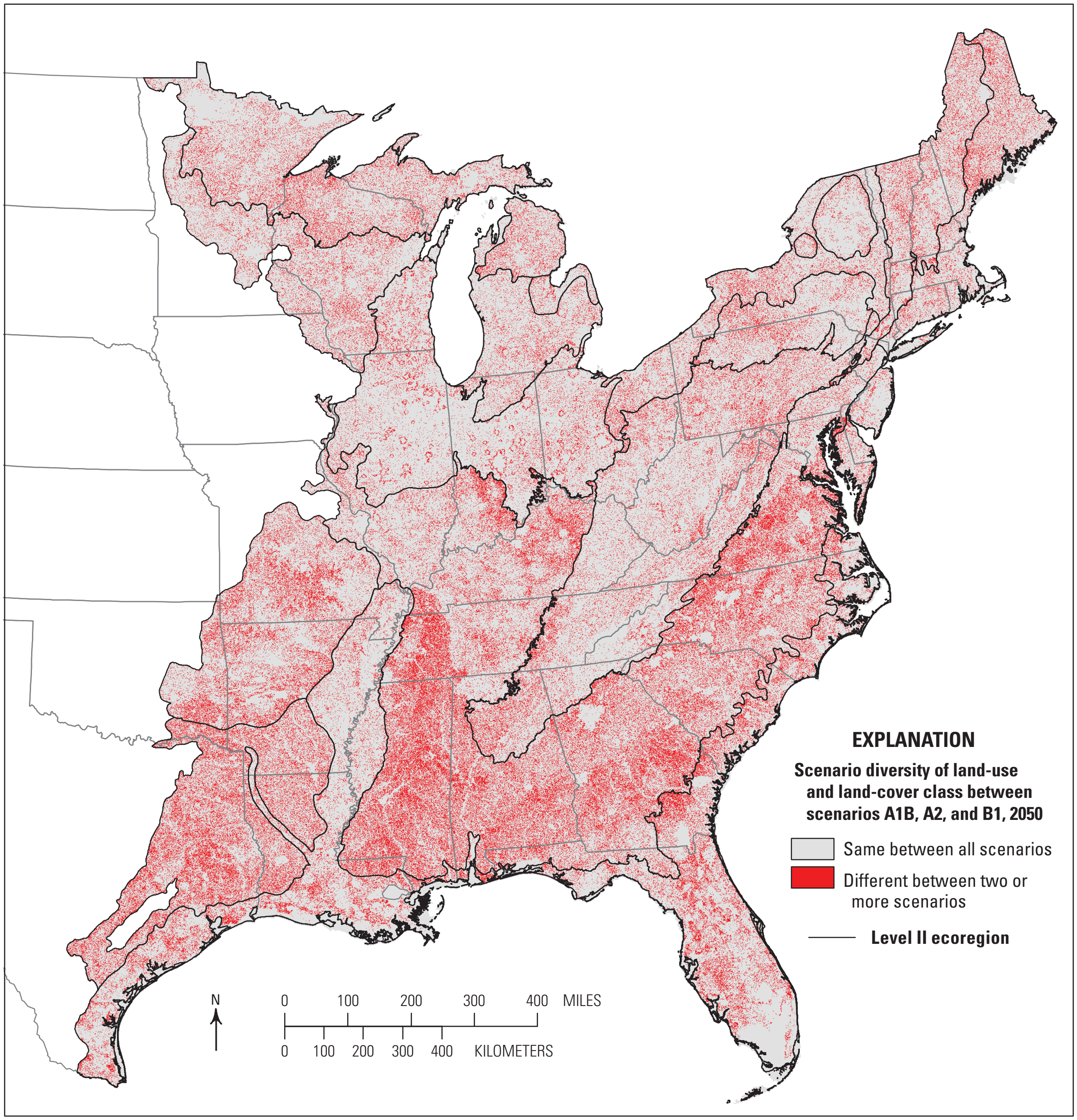


Figure 3–17. Map showing the spatial diversity between three land-use and land-cover scenarios (Nakićenović and others, 2000) in the Eastern United States in 2050.